DEPARTMENT OF THE ARMY
U.S. ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE
5158 BLACKHAWK ROAD
ABERDEEN PROVING GROUND, MARYLAND 21010-5422

REPLY TO
ATTENTION OF

US Army Center for Health Promotion and
Preventive Medicine
5158 Blackhawk Road, Bldg 1677
Aberdeen Proving Ground, MD 21010-5422

July 7, 1997

Dear Citizen's Advisory Panel member:

Enclosed is the Health Risk Assessment Protocol, Project No. 39-EJ-6995-97, Open Burning of Propellant Bags, Massachusetts Military Reservation. The purpose of this protocol is to present the methodology for a site-specific multi-pathway human health risk assessment for exposure to emissions from past propellant bag burning at Massachusetts Military Reservation (MMR).

This protocol is provided for review and comment. The comment period will extend from 8 July 1997 to 8 September 1997. Please review this protocol and provide comments and recommendations by 8 September 1997 to:

U.S. Army Center for Health Promotion and Preventive Medicine
ATTN: MCHB-DC-EHR (CPT Deborah Hastings)
5158 Blackhawk Road, Bldg 1677
Aberdeen Proving Ground, MD 21010-5422

Mr. Don Consolmagno, Public Affairs Officer, Massachusetts Military Reservation, Bldg 1204, can be reached for questions during the comment period at (508) 968-5824.

Sincerely,

Dale R. Bowler Jr.
for Dennis Druck
Acting Program Manager
Environmental Health Risk and
Risk Communication Program

Readiness thru Health

USACHPPM

U.S. Army Center for Health Promotion and Preventive Medicine

Protocol

RISK ASSESSMENT NO. 39-EJ-6995-97
OPEN BURNING OF PROPELLANT BAGS
MASSACHUSETTS MILITARY RESERVATION
CAPE COD, MASSACHUSETTS

JULY 1997

Readiness Thru Health

U.S. ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE

The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) lineage can be traced back over a half century to the Army Industrial Hygiene Laboratory which was established at the beginning of World War II under the direct jurisdiction of The Army Surgeon General. It was originally located at the Johns Hopkins School of Hygiene and Public Health with a staff of three and an annual budget not to exceed three thousand dollars. Its mission was to conduct occupational health surveys of Army-operated industrial plants, arsenals, and depots. These surveys were aimed at identifying and eliminating occupational health hazards within the Department of Defense's (DOD) industrial production base and proved to be extremely beneficial to the Nation's war effort.

Most recently, the organization has been nationally and internationally known as the U.S. Army Environmental Hygiene Agency (AEHA) and is located on the Edgewood area of Aberdeen Proving Ground, Maryland. Its mission had been expanded to support the worldwide preventive medicine programs of the Army, DOD and other Federal agencies through consultations, supportive services, investigations and training.

On 1 August 1994, the organization was officially redesignated the U.S. Army Center for Health Promotion and Preventive Medicine and is affectionately referred to as the CHPPM. As always, our mission focus is centered upon the Army Imperatives to that we are optimizing soldier effectiveness by minimizing health risk. The CHPPM's mission is to provide worldwide scientific expertise and services in the areas of:

- Clinical and field preventive medicine
- Environmental and occupational health
- Health promotion and wellness
- Epidemiology and disease surveillance
- Related laboratory services

The Center's quest has always been one of customer satisfaction, technical excellence and continuous quality improvement. Our vision is to be a world-class center of excellence for enhancing military readiness by integrating health promotion and preventive medicine into America's Army. To achieve that end, CHPPM holds everfast to its core values which are steeped in our rich heritage:

- Integrity is our foundation
- Excellence is our standard
- Customer satisfaction is our focus
- Our people are our most valuable resource
- Continuous quality improvement is our pathway

Once again, the organization stands on the threshold of even greater challenges and responsibilities. The CHPPM structure has been reengineered to include General Officer leadership in order to support the Army of the future. The professional disciplines represented at the Center have been expanded to include a wide array of medical, scientific, engineering, and administrative support personnel.

As the CHPPM moves into the next century, we are an organization fiercely proud of our history, yet equally excited about the future. The Center is destined to continue its development as a world-class organization with expanded preventive health care services provided to the Army, DOD, other Federal agencies, the Nation, and the world community.

Health Risk Assessment Protocol
Open Burning of Propellant Bags
Massachusetts Military Reservation, MA
Project No. 30-EJ-6995-97

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July 1997

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Submitted by:

United States Army Center for Health Promotion Medicine
and Preventive Medicine
Aberdeen Proving Ground, MD 21010-5422

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Acronyms and Abbreviations

ATSDR	Agency of Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
$CaCO_3$	calcium carbonate
CARB	California Air Resources Board
C/DR	concentration and deposition rates
cm	centimeter
COC	chemicals of concern
CRS	Congressional Research Service
CSF	cancer slope factor
CSM	conceptual site model
DNT	dinitrotoluene
DPA	diphenylamine
DPG	Dugway Proving Grounds
ECAO	Environmental Criteria and Assessment Office
°F	temperature in degrees Fahrenheit
HCB	hexachlorobenzene
HCl	hydrogen chloride
HEAST	health effects assessment summary tables
Hg	mercury
HI	hazard index
HQ	hazard quotient
HQ_{inh}	inhalation hazard quotient for substance, unitless
hr	hour
HHRA	human health risk assessment
IED	indirect exposure document
IEDA	indirect exposure document addendum
IG	Implementation Guidance
IRIS	integrated risk information system
ISCST3	Industrial Source Complex - Short Term, Version 3, Model
K_{ow}	octanol/water partition coefficient
kg	kilogram
km	kilometer
L	liter
LOAEL	lowest observed adverse effect level
MAANG	Massachusetts Army National Guard
MADEP	Massachusetts Department of Environmental Protection
MADPH	Massachusetts Department of Public Health
mg	milligram
MMR	Massachusetts Military Reservation
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Science
NAWQC	National Ambient Water Quality Criteria

NEL	no effect level
NG	nitroglycerin
NOAEL	no observed adverse effect level
NRC	National Research Council
OANGB	Otis Air National Guard Bases
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science and Technology Policy
P_C	particulate air concentration
P_{DD}	particulate dry deposition
P_{WD}	particulate wet deposition
PAVE-PAWS	Precision Acquisition Vehicle Entry Phased Array Warning System
PCBs	polychlorinated biphenyls
PICs	products of incomplete combustion
PM	particulate matter
PM_{10}	particulates equal to or less than 10 μm
POHCs	products of hazardous combustion
RA	risk assessment
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration, mg/m^3
RfD	reference dose
RfD_i	reference dose for substance I, mg/kg/day
SEL	severe effect level
SQB	sediment quality benchmark
SRI	Southern Research Institute
SVOC	semi-volatile organic compounds
TEF	toxic equivalency factor
TEQ	toxicity equivalence
TIC	tentatively identified compounds
TRV	Toxicity Reference Value
TSC	USEPA Superfund Health Risk Technical Support Center
UR	unit risk
USACE	U.S. Army Corps of Engineers
USAEHA	U.S. Army Environmental Hygiene Agency
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
V_C	vapor air concentration
V_{WD}	vapor wet deposition
VOC	volatile organic compound
WQB	water quality benchmarks
yr	year

1.0 INTRODUCTION

1.1 Project Scope and Objective

This document outlines the procedures that will be followed in conducting a multi-pathway human health risk assessment (HHRA) which will evaluate direct and indirect, cancer risks and chronic non-cancer hazards associated with the past practice of open burning of propellant bags during training at the Camp Edwards portion of Massachusetts Military Reservation (MMR).

Camp Edwards is used by the Massachusetts Army National Guard (MAANG) and the United States Army Reserve for training purposes. This training includes the firing of mortars and artillery. Until 1992, both unused mortar and artillery propellant was disposed of via open burning at gun points during each training exercise (ATSDR, 1994).

In January 1992 a Boston University study investigated an increased incidence of cancer in the upper Cape Cod region. Several potential sources of environmental contamination, including the Canal Electric Plant, Barnstable Airport, and propellant bag burning at MMR, were identified (Boston University School of Public Health, 1991). Based on recommendations from the Agency of Toxic Substances and Disease Registry (ATSDR), the MAANG voluntarily stopped burning artillery propellants (MADEP, 1994). The burning of mortar propellants continued until 1997 when all firing exercises at MMR were ceased.

The MAANG agreed to conduct an air monitoring study at MMR. Because of public concern over the potential health effects of a test burn, the MAANG agreed to allow the test burn to be conducted in a facility away from Camp Edwards. The test burn was conducted at Dugway Proving Grounds in a Bang Box test facility. The Bang Box test facility was specifically designed for open burning and open detonation emissions testing. Data from the test burning was used to develop chemical emission rates from the burning of artillery and mortar propellants. These emission rates will be used in the HHRA as described in this protocol.

This study is response to Recommendation Number Seven contained in the Agency for Toxic Substances and Disease Registry Public Health Assessment for Otis Air National Guard Base/Camp Edwards dated January 25, 1994 (ATSDR, 1994). The recommendation read, "Refrain from the practice of propellant bag burning until a test burn is conducted with concurrent air monitoring at a location and in a manner that would not place residents at public health risk." This study addresses that recommendation by incorporating the results of the Bang Box test into a HHRA. In addition, this assessment will be an extension of a previous health risk study completed by the U.S. Army Environmental Hygiene Agency (now USACHPPM) titled, "Health Risk Assessment Concerning Open Burning of Gun Propellants, No. 65-32-0716-91, Camp Edwards, Massachusetts, 17 May 1991 (USAEHA, 1991).

1.2 Human Health Risk Assessment Methodology

The technical approach described in this protocol is designed to provide estimates of individual risk, and risks to highly exposed or susceptible sub-populations.

In general, the direct and indirect risks and hazards will be estimated with a screening hierarchy. The initial assessment will be based upon current U.S. Environmental Protection Agency (USEPA) guidance and recommendations, as well as the Massachusetts Military Reservation Risk Assessment Handbook (1994), which will provide a conservative estimate of site risks and hazards. This approach includes the use of numerous default values. If appropriate and defensible, the analysis may move away from selected default values to values which are more specific to the MMR characteristics.

If the initial assessment indicates that further analysis is needed, a tiered approach, as described in the MMR Risk Assessment Handbook, will be implemented to refine risk estimates. This approach will include local demographic parameters and the evaluation of additional pathways. The phased approach was developed to provide the most conservative estimates possible while still focusing on realistic exposure scenarios.

The initial risk evaluation and phased risk evaluation, if needed, will follow the fundamental paradigm adapted by USEPA from well-established chemical risk assessment principles and procedures (Congressional Research Service, 1983; National Academy of Sciences, 1983; Office of Science and Technology, 1985). The USEPA paradigm currently includes five major components which were adopted to provide a consistent process for evaluating and documenting health risks. These major components include: data collection and evaluation; exposure assessment; toxicity assessment; risk characterization; and uncertainty analyses:

- Data Collection and Evaluation: The collection of pertinent information and determination of the substances which may impact human health or the environment.

- Exposure Assessment: Definition of the study area, identification of potentially exposed individuals, identification of how a person may potentially contact a substance (exposure pathway), estimation of the concentration of each substance in the media, and estimation of the amount of substance to which each individual may have been exposed (intake or dose).

- Toxicity Assessment: The determination of health effects of chemical substances and the quantification of those effects.

- Risk Characterization: The quantification of risk estimates at a site determined by combining exposure information with toxicity information.

- Uncertainty Analysis: the summarization of how variability and uncertainty may affect the numbers generated in the risk assessment and the conclusions drawn.

The risk assessment methodology will comply with key USEPA guidance (see references) including, but not limited to:

- *Methodology for Assessing Health Risk Associated with Indirect Exposure to Combustor Emissions.* This document will be referred to as the Indirect Exposure Document (IED). 1990.

- *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* This document will be referred to as the Indirect Exposure Document Addendum (IEDA). 1993.

- *Revised Draft of Risk Assessment Implementation Guidance for Hazardous Waste Combustion Facilities.* This document will be referred to as the Implementation Guidance (IG). 1994.

- Errata Sheet, *Revised Draft of Risk Assessment Implementation Guidance for Hazardous Waste Combustion Facilities.* This document will be referred to as the Errata Sheet. 1994.

- *Derivation of Time-Average Soil Concentration Equations.* This document will be referred to as the Soil Averaging Addendum. 1994.

- *Risk Assessment for Superfund, Volume I, Human Health Evaluation Manual, Part A* (RAGS). 1989.

- *Exposure Factors Handbook.* 1989.

- *Guidelines for Exposure Assessment.* 1992.

- *Guidance on Risk Characterization for Risk Managers and Risk Assessors.* 1995.

- *Further Issues for Indirect Exposure Assessment Modeling.* This document will be referred to as the Further Issues Memorandum. 1994.

1.3 MMR Background

1.3.1 Location and Topography

Camp Edwards is part of MMR, and is located in Upper Cape Cod, Massachusetts (see Figure 1-1). The MMR is a multi-purpose training installation that occupies approximately 22,000 acres on the western side of Cape Cod, in Barnstable County. MMR lies within the towns of Bourne, Mashpee, Falmouth, and Sandwich (ATSDR, 1994). The reservation is approximately 60 miles south-southeast of Boston and immediately south of the Cape Cod Canal (ATSDR, 1994).

1.3.2 History and Mission

Several military branches operate at MMR, including the U.S. Coast Guard (USCG), the MAANG, the U.S. Air Force (USAF), the Veterans Administration (VA), and the Massachusetts Air National Guard (ATSDR, 1994). Otis Air National Guard Base (OANGB) is located in the southern portion of MMR.

Military activity began at Cape Cod in 1911. Two types of operations have dominated military activity at MMR: 1) mechanized army training, maneuvers, and maintenance support; and 2) military aircraft operations, maintenance, and support. Most of the military activity has occurred since 1935 and has involved Army infantry maneuvers and aircraft operations. Currently, the military uses the facility for training. The USCG also launches search and rescue missions from the base (ATSDR, 1994).

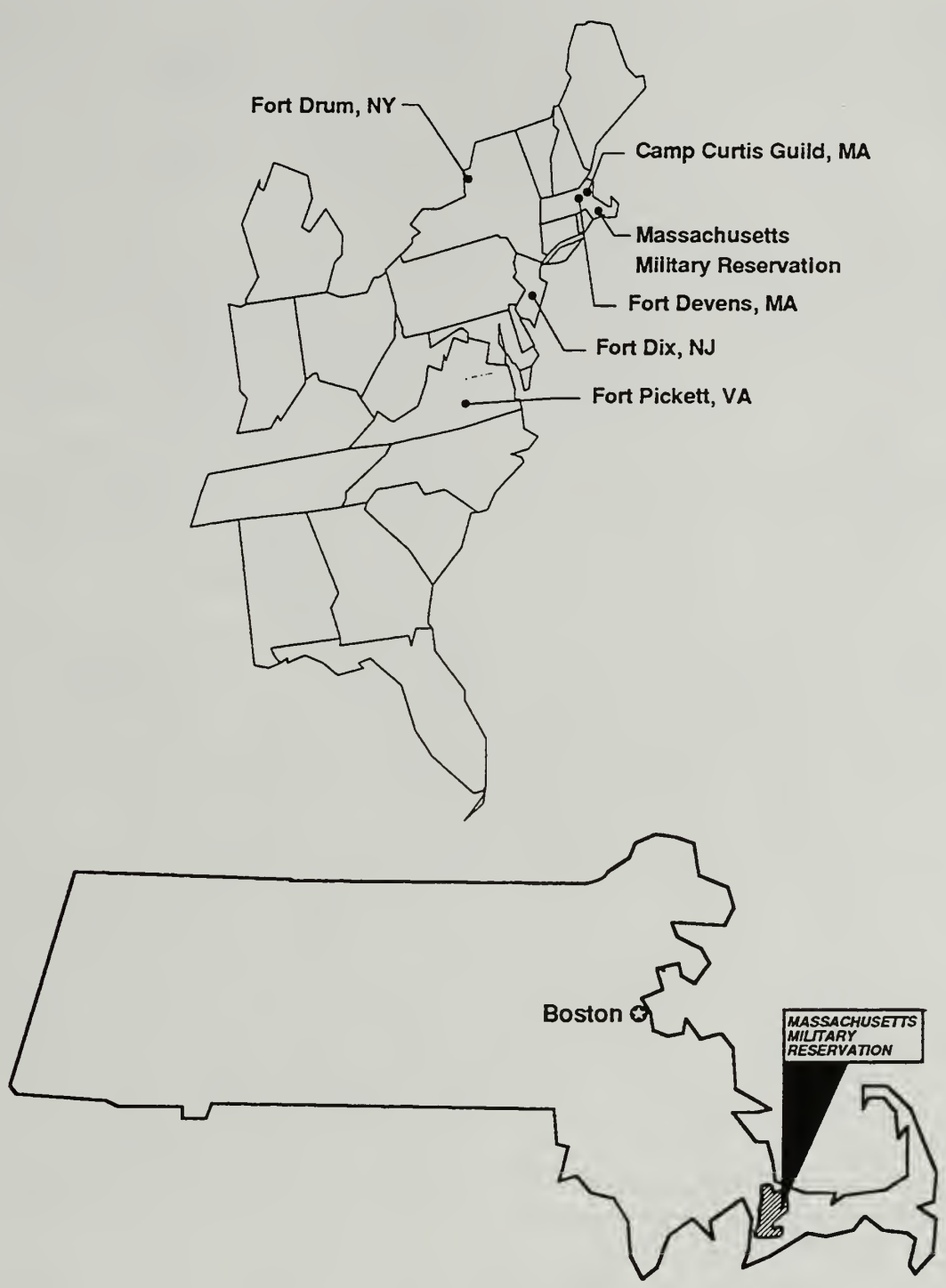
The cantonment area (see Figure 1-2) has been the most actively used area of the reservation. During WWII, the Army used the cantonment area to service large motor pools (up to 400 vehicles). Levels of activity were highest in the cantonment between 1955 and 1972 when USAF surveillance and air defense units were stationed at MMR (ATSDR, 1994).

1.3.3 Facilities and Layout

The majority of the facilities at MMR are located in the southern part of the installation. The northern 70 percent of MMR houses the artillery range and the maneuver and impact area of Camp Edwards, as well as the USCG Transmitter Facility and Cape Cod Air Force Station. Although several military branches operate at MMR, 90 percent of the land is owned by the state of Massachusetts (ATSDR, 1994).

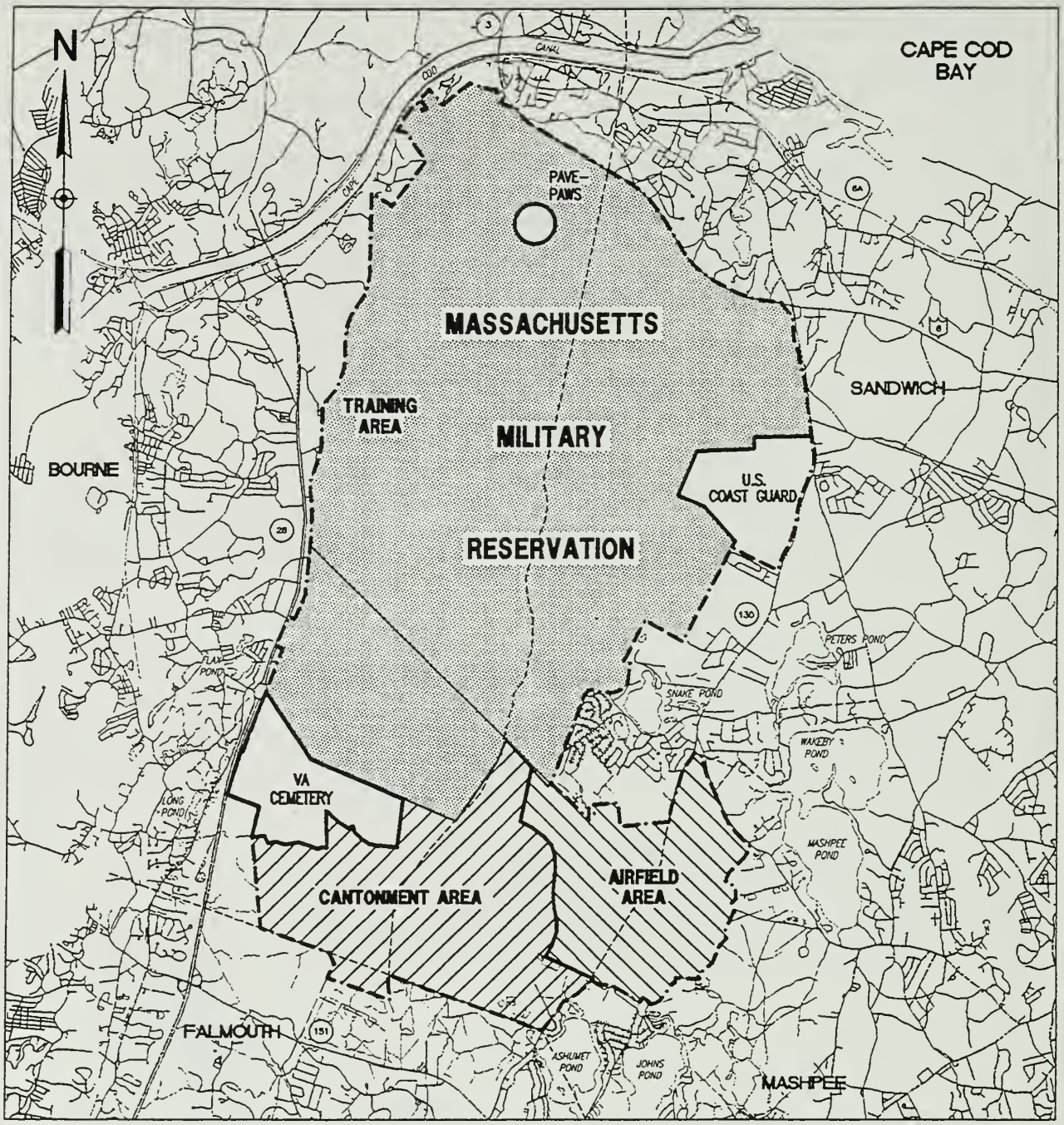
MMR is composed of three main areas: a 14,236 acre range, maneuvers, and impact area; a 750-acre VA cemetery; and a 5,000-acre cantonment area on the southern portion of the MMR. The 87-acres Cape Cod Air Force Station, commonly known as Precision Acquisition Vehicle Entry-Phased Array Warning System (PAVE-PAWS), is also located in the northern

Figure 1-1



SITE LOCATION EVALUATION AND MMR VICINITY MAP

Figure 1-2



LEGEND

- TOWN BOUNDARY
- INSTALLATION BOUNDARY
- US/STATE HIGHWAY
- TRAINING AREA
- CANTONMENT AREA
- AIRFIELD AREA
- OTHER USE

0 4000 8000 FEET

1"=8000'

Source: Massachusetts Military Reservation

SITE LOCATION MAP

portion of the range area (see Figure 1-2). The PAVE-PAWS radar facility has been used by the USAF since 1978 to detect sea-launched ballistic missiles. The VA cemetery, also known as the Massachusetts National Cemetery, is on the western edge of the reservation (ATSDR, 1994).

1.3.4 Demographics and Land Use

The upper portion of Cape Cod is 212 square miles and encompasses the towns of Barnstable, Bourne, Falmouth, Mashpee, and Sandwich. The area had a 1990 population of 98,346. The population of the Upper Cape towns increased approximately 22 percent from 1980 to 1990. A large proportion of the population, (19.6% overall) is persons aged 65 and older. The population of the entire Cape Cod area nearly triples during summers due to the influx of vacationers (ATSDR, 1994).

Approximately 2,400 people live in on-post housing and 1,150 people, both military and civilian, are full-time employees. Additionally, two contractors have full-time employees on-site. In order to carry out its function as an Air National Guard facility, OANGB employs approximately 1,200 part-time military personnel who work an average of 39 days each year.

On-post residents live in the 631 family units on the southwestern portion of the reservation. Most of the housing area was built in the late 1950s. Occupied largely by Coast Guard families, it includes a grocery annex, a post exchange store, a gas station, and four schools. Three of these schools, Otis Memorial (grades K-3), Stone Middle School (grades 4-6), and Lyle School (grades 7 and 8), are part of the Bourne School Department. Approximately 1,000 students from both on and off post attend these schools. The fourth school is closed. There are two ponds and approximately 20 playgrounds in the housing area. There is a golf course east of the housing area. A day care center and a health clinic are currently operating on-post (ATSDR, 1994).

Groundwater is the major source of potable water in the area. Residential wells and several municipal supply wells are located in the Upper Cape. Three freshwater ponds south of the reservation are used for swimming, fishing, and boating. Ashumet Pond and Johns Pond are in the Briarwood neighborhood; Coonamessett Pond is west of these ponds. Snake and Weeks Ponds, located to the east of the installation, are used for recreational purposes. (ATSDR, 1994).

Twenty percent of MMR is developed land. The remaining 80 percent is the artillery range, which is undeveloped. This area consists of gunnery areas and an artillery impact area. Vegetation in this area is periodically burned off for fire control. Two ponds, Osborne and Edmunds Ponds, are located in this area (ATSDR, 1994).

1.4 Description of the Propellant Bag Burning Process

1.4.1 Background

Propellant bag burning has been conducted by both U.S. Army National Guard and U.S. Army Reserve personnel as part of training exercises at MMR. The burning of artillery

propellants which contain 2,4-dinitrotoluene was stopped voluntarily in 1992. Each artillery and mortar round comes supplied with the standard maximum charge of propellant in a specific number of propellant bags. If all propellant bags provided were used, the projectiles would be propelled beyond the designated impact area. Manufacturers do not currently provide propellant packs for restricted land use training, therefore excess propellant bags were disposed.

1.4.2 Process Description

The excess propellant bags were collected each day at each firing point and were burned in the immediate proximity (USAEHA, 1987). Within the MMR training areas there are eleven separate mortar points where mortar propellant was burned and sixteen separate gun points where artillery propellant was burned (see Figure 1-3). To burn the excess propellant, the unused bags (or charges) were typically arranged in lines varying from 5 to 15 feet in length and less than 1 foot in width (USAEHA, 1987). A small amount of propellant powder was laid at one end of the line to act as a fuse.

The burning of propellant bags involves the rapid oxidation of the propellants with a release of heat and products of combustion. When the bags are burned, there is a rapid conversion of solid materials into gaseous end products, particulate matter, and some nonvolatilized residue. The composition of the emissions to the ambient air depends upon the type of propellant being burned; combustion parameters (e.g. temperature, turbulence); and atmospheric conditions.

1.4.3 Types of Propellants Used at Camp Edwards

There are three primary categories of propellants: single-based, double-based, and triple-based. Single-based propellants are composed primarily of nitrocellulose, double-based propellants are composed primarily of nitrocellulose and nitroglycerin, and triple-based propellants are composed primarily of nitrocellulose, nitroglycerin, and nitroquanidine. Triple-based propellants were not used at Camp Edwards.(MAANG, 1994)

The single-based M1 propellant was used at Camp Edwards for firing artillery projectiles from the 155-mm howitzer. Historically, this propellant was also used when firing the 105-mm howitzer. Table 1-1 presents the nominal composition of M1 propellant. The M1 propellant pack (called M3/green bags) used in the 155-mm howitzer is configured into five different charge bags. The five bags are different sizes and have slightly different chemical compositions (e.g., the first bag contains an igniter and bags four and five have a flash reducer (lead foil)). The M1 propellant pack (called M67) used in the 105-mm howitzer is configured into seven different charge bags. Again, the bags have different sizes and slightly different chemical compositions (See Table 1-2). Because of the land use restrictions at MMR, normally only the first three charge bags were used when firing from the gun points surrounding the impact area. Therefore, charge bag numbers four and five for the 155-mm gun and charge bag numbers four through seven for the 105-mm gun were usually open burned at each of the gun points.

Figure 1-3. Firing Point Locations in the Camp Edwards Training Area

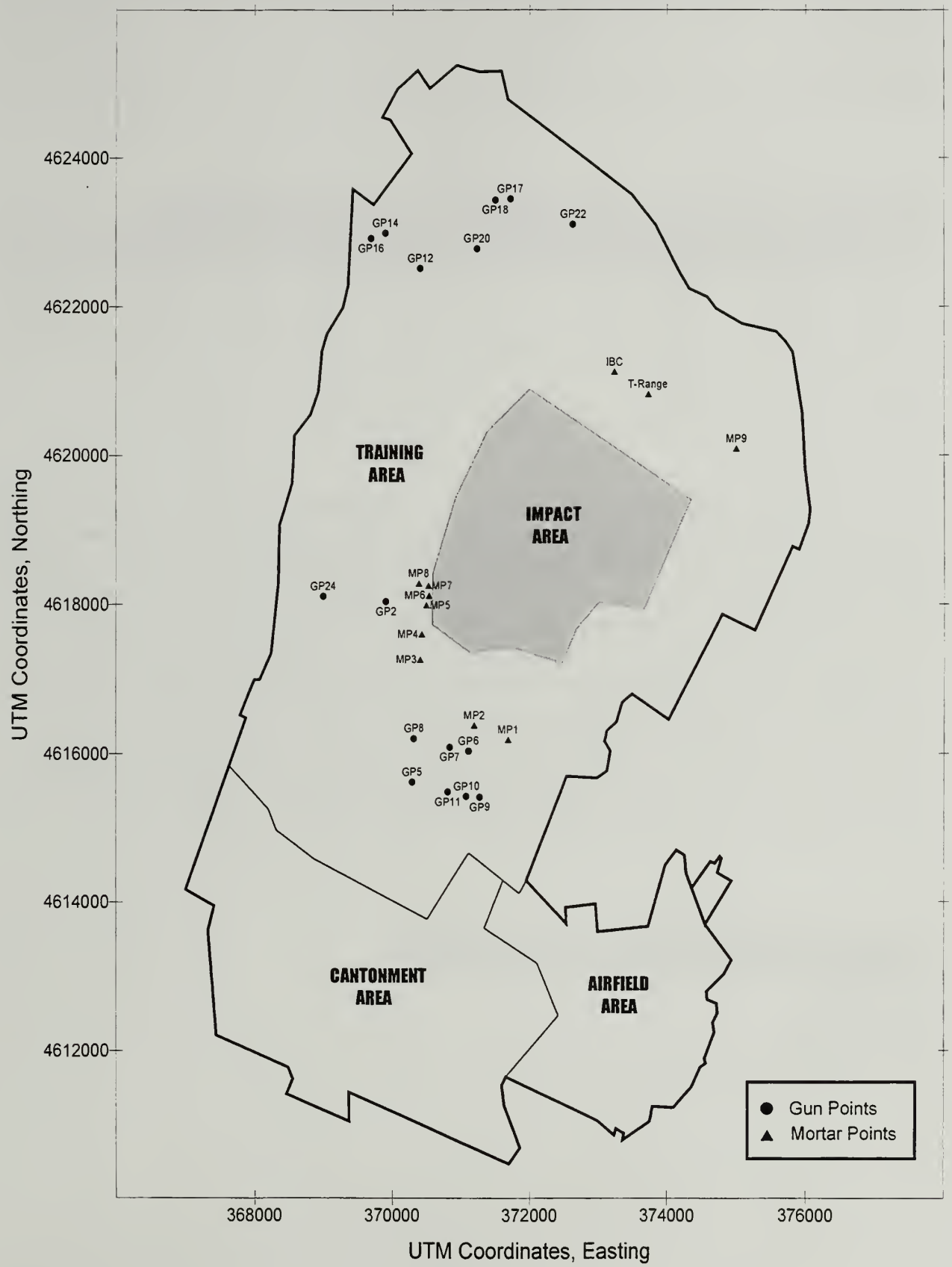


Table 1-1. Nominal Composition of M1 Propellant

Compound	*Percentage of Total Weight*
Nitrocellulose	84.20
Dinitrotoluene	9.90
Dibutylphthalate	4.90
Diphenylamine	1.00

Table 1-2. Comparison of Howitzer charges (Both Contain M1 propellant)

Charge Number	*M67 (Used in 105 mm) Weight by charge (grams)*	*M3/Green Bags (Used in 155 mm) Weight by charge (grams)*
1	234.7	884.5
2	39.7	224.0
3	76.3	292.0
4	104.9	405.4
5	146.6	688.9
6	244.1	N/A
7	399.2	N/A

The double-based M9 propellant was used at Camp Edwards for firing 81-mm and 4.2-in (107-mm) mortar cartridges. The similar, double-based M8 propellant was used for the 60-mm high explosive rounds and was also part of the propellant used for the 4.2-in mortars. Tables 1-3 and 1-4 present the nominal composition of M9 and M8 propellant, respectively. Table 1-5 contains the descriptions of the propellant packs included with the mortars that were used at Camp Edwards. The M9 propellant pack (called M90A1) is configured into nine charge increments (or bags) of the same size. Each bag is of similar chemical composition and contains approximately 10.5 grams of propellant. The M8 propellant pack (called M3A1, M181, or M182) is configured into four bags of equal weight and size. Each bag is of similar chemical composition and contains approximately 2.8 grams of propellant. The propellant pack for the 4.2-inch mortar is made up of 41 rectangular increments (referred to as "cheese") each of equal size and weight. Each charge increment contains approximately 7.6 grams of propellant.

Table 1-3. Nominal Composition of M9 Propellant

Compound	*Percentage of Total Weight*
Nitrocellulose	57.75
Nitroglycerin	40.00
Potassium Nitrate	1.50
Diphenylamine	0.75

Table 1-4. Nominal Composition of M8 Propellant

Compound	*Percentage of Total Weight*
Nitrocellulose	52.15
Nitroglycerin	43.00
Diethylphthalate	3.00
Potassium Nitrate	1.25
Ethylcentralite	0.60

Table 1-5. Mortars and Propellant Used at Camp Edwards

Mortar Type	*Propellant Type*	*Number of Increments*	*Weight Per Increment (grams)*	*Increment Configuration*
81-mm	M9	9	10.5	Bags
60-mm	M8	4	2.8	Bags
4.2-in (107-mm)	M9/M8	41	7.6	"Cheese"

2.0 DETERMINATION OF AIR CONCENTRATIONS AND DEPOSITION RATES

2.1 Introduction

The determination of ambient air concentrations as well as surface deposition rates from propellant bag burning emissions depends upon many factors including meteorology, location and frequency of the burning, amount and type of propellant burned, and the specific combustion products formed from burning the propellant. An air dispersion model will be used to predict the concentrations and deposition rates from past operations. These operations will be defined using historical meteorology and burn data as well as a specific emissions characterization. The following sections will discuss these factors in more detail.

2.2 Meteorological Data

The historical meteorology data is important in predicting the ambient concentrations and surface deposition rates because specific meteorological conditions (wind speed, wind direction, air temperature, precipitation, etc.) are necessary for the model to calculate hourly concentrations and deposition rates. The meteorological data will be obtained from the Air Force Combat Climatology Center which is the military equivalent to the civilian National Climatic Data Center. Surface data will be compiled from the local met station at Otis Air National Guard Base for the ten-year period 1985-1994, and the precipitation data will be compiled for the same years from Hyannis, MA. Upper air data will be compiled from Albany, New York which is the nearest upper air station with complete data from 1985-1994. This ten year time period was chosen because it coincides with the years that specific burn data are available.

2.3 Propellant Burn Data

Propellant burn information has been collected from records kept by the MMR environmental office since 1986. This data (see Appendix C, Tables C-2 to C-16) has been organized by ammunition type (mortar or artillery), amount burned per year, and if known, firing point utilized. Because of the different chemical composition of artillery and mortar propellant, a separate health risk analysis will be done for burning each type of propellant, M1 and M9. For the purposes of this study, all mortar propellant burned at Camp Edwards will be considered to be M9 propellant because the M8 propellant has a very similar chemical composition to M9 propellant (see Tables 1-3 and 1-4). Furthermore, all artillery propellant will be assumed to be M1 propellant since M1 propellant is used for firing both 105mm and 155mm howitzers.

An annual average of M1 and M9 propellant burned at Camp Edwards is shown in Table 2-1. The burning of M1 propellant at Camp Edwards was stopped in March 1992, and none was burned during January to March of that same year. The data records for 1987 and 1990 only included half of the year, therefore, the amount recorded for those years was doubled to account for this lack of data.

Table 2-1. Annual Propellant Burned at Camp Edwards

Year	*M1 Propellant (lbs)*	*M9 Propellant (lbs)*
1986	10631	952
1987	6715*	291*
1988	2712	324
1989	4029	1699
1990	2978*	259*
1991	3893	1595
1992	0	425
1993	0	692
1994	0	292
Annual Average	**5160** (Based on 6 years)	**725** (Based on 9 years)

* Double the amount found in the records to account for lacking data

An annual average of firing point utilization is shown in Tables 2-2 and 2-3. The percentages in the tables represent the fraction of total propellant burned at Camp Edwards at each firing point. The data records for 1987 and 1988 did not include firing point utilization. The average firing point utilization will be combined with the overall average propellant burned to determine an average amount of propellant burned at each site.

Table 2-2. Annual Gun Point Utilization at Camp Edwards*

Gun Point	*1986*	*1989*	*1990*	*1991*	*Annual Average*
GP2	0.0%	0.0%	0.0%	0.0%	0.0%
GP5	0.0%	0.0%	0.0%	0.0%	0.0%
GP6	13.4%	8.9%	16.7%	18.1%	14.3%
GP7	8.8%	7.5%	25.5%	6.3%	12.0%
GP8	9.9%	4.2%	4.5%	6.9%	6.4%
GP9	15.4%	6.8%	6.5%	9.9%	9.6%
GP10	8.7%	9.7%	6.2%	8.5%	8.3%
GP11	6.4%	8.6%	0.0%	7.7%	5.7%
GP12	0.8%	4.5%	0.0%	3.1%	2.1%
GP14	7.3%	6.7%	11.5%	10.2%	8.9%
GP16	8.2%	10.9%	4.7%	5.6%	7.4%
GP17	0.8%	2.6%	0.0%	3.9%	1.8%
GP18	3.1%	2.6%	7.2%	0.0%	3.2%
GP20	8.4%	13.0%	13.0%	10.6%	11.2%
GP22	6.6%	14.0%	4.2%	8.1%	8.2%
GP24	2.2%	0.0%	0.0%	1.1%	0.8%

* Percentage based upon total amount of propellant burned for each year

Table 2-3. Annual Mortar Point Utilization at Camp Edwards*

Mortar Point	*1986*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Annual Average*
MP1	6.9%	6.1%	24.9%	23.6%	10.4%	9.8%	12.0%	13.4%
MP2	10.0%	25.4%	2.9%	0.7%	10.9%	2.8%	16.9%	10.0%
MP3	39.4%	16.7%	12.1%	34.8%	19.2%	30.5%	21.8%	24.9%
MP4	10.8%	29.5%	4.7%	14.6%	19.8%	24.3%	12.0%	16.5%
MP5	4.8%	7.8%	0.0%	0.0%	4.9%	3.1%	0.0%	2.9%
MP6	21.8%	4.8%	11.0%	7.8%	6.6%	13.4%	15.4%	11.5%
MP7	4.4%	5.5%	31.2%	8.9%	5.5%	1.9%	8.2%	9.4%
MP8	0.0%	4.2%	10.1%	3.3%	22.6%	14.2%	13.7%	9.7%
MP9	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
IBC	0.0%	0.0%	0.0%	3.7%	0.0%	0.0%	0.0%	0.5%
T-Range	1.7%	0.0%	3.1%	2.2%	0.0%	0.0%	0.0%	1.0%

* Percentage based upon total amount of propellant burned for each year

2.4 Emission Factor Determination

2.4.1 Bang Box Facility

In order to characterize the emissions associated with propellant burning, a series of propellant burns were conducted between 16-18 March 1993 in the Bang Box Facility at Dugway Proving Ground (DPG). The DPG Bang Box Facility is a permitted test facility specifically designed for the burning/detonation of small quantities of propellants/explosives. During the controlled tests in the Bang Box, DPG personnel burned the same propellant bags that are normally burned at Camp Edwards while replicating the temperature and relative humidity conditions typically found on the installation (MAANG, 1994). Separate tests were conducted burning M1 propellant (used in artillery firing) and M9 propellant (used in mortar firing). Because triple based propellants were not used at Camp Edwards they were not used in the Bang Box analysis.

The burns were conducted in accordance with a detailed test plan prepared by the U.S. Army Environmental Hygiene Agency (USAEHA, 1993). The test plan was reviewed extensively by the Massachusetts Department of Environmental Protection (MADEP), Massachusetts Department of Public Health (MADPH), and EPA Region I prior to acceptance. Representatives from the EPA Region I, MADEP, MADPH, and the Barnstable County Health Department were onsite to witness the test and to verify that air sampling was conducted properly.

2.4.2 Emissions Characterization

Table 2-4 contains the list of chemicals that were identified and quantified in the Bang Box burn trials for both M1 and M9 propellants. As a further characterization of emissions, an emission factor was calculated for each chemical every time it was detected in a valid sample. These emission factors will be the basis for determining chemical-specific air concentrations and surface deposition rates. Background sampling was conducted immediately prior to testing to

identify any indigenous ambient contaminants which may have been present in the Bang Box facility. A series of five trials were used to determine emission factors from burning M1 propellant (M3/green bags) and one trial was used to determine emission factors from burning M9 propellant (MAANG, 1994). Table 2-4 also contains the number of samples (and therefore the number of emission factors) that were evaluated for each compound present in the M1 and M9 propellant burns. The following paragraphs describe the sampling methodology that was employed to characterize the emissions from the Bang Box at DPG.

The volatile organic compounds (VOCs) were collected using one 6-liter stainless steel canister; therefore, five samples were obtained for the M1 propellant burns and one sample was obtained for the M9 propellant burn. For metals emissions, three high volume (HiVol) samplers were used for each trial; therefore, fifteen samples were taken during the M1 propellant burns and three samples were taken during the M9 propellant burn. The semivolatile organic compounds (SVOCs) were collected using two separate sampling methods: three HiVol samplers and three PS-1 samplers. Therefore, thirty SVOC samples were taken during the five M1 propellant burns and six samples were taken during the M9 propellant burn. The HCl and HCN sampler measured HCl during the M9 propellant burn and the first M1 propellant burn and measured HCN during the last four M1 propellant trials. PM_{10} was sampled during all six burns.

Two different analytical methods were used to measure the concentrations of the SVOCs. The EPA Method 8270 (gas chromatograph/mass spectrometer) was used as the general analytical method, while supercritical fluid chromatography/ mass spectrometry (SFC/MS) was used for specific, thermally liable compounds like RDX, HMX, 2,4-DNT, and 2,4,6- TNT. The combination of two different samplers and two different analytical methods used to identify SVOC emissions resulted in some compounds having as many as 45 samples analyzed.

Table 2-4. Identified Chemicals from M1 and M9 Propellant Test Burns

Chemical	*# of Samples M1 Propellant*	*# of Samples M9 Propellant*
Volatile Organics:		
Benzene	5	1
Carbon Tetrachloride	5	1
Ethylbenzene	5	N/D*
Methane	5	N/D
n-Propylbenzene	5	N/D
Styrene	N/D	1
Toluene	5	N/D
m&p-Xylene	5	N/D
o-Xylene	5	N/D
Semi-Volatile Organics:		
Acenaphthylene	15	3
Acetophenone	30	3
4-Aminobiphenyl	15	N/D
Benzo[a]anthracene	15	N/D
Benzo[a]pyrene	15	3
Benzo[b]fluoranthene	15	N/D
Benzo[ghi]perylene	15	N/D
Benzoic Acid	15	N/D
bis(2-Ethylhexyl)phthalate	30	3
Butyl benzyl phthalate	30	3
Dibenzofuran	30	3
Diethyl phthalate	30	3
a,a-Dimethylphenethylamine	15	3
2,4-Dimethylphenol	15	N/D
Dimethyl phthalate	30	3
Di-n-butyl phthalate	30	3
2,4-Dinitrotoluene	45	N/D
Di-n-octyl phthalate	30	3
Diphenylamine	15	3
Fluoranthene	30	N/D
RDX	15	3
2-Methylnaphthalene	15	3
Naphthalene	15	3
2-Nitrodiphenylamine	15	N/D
2-Nitrophenol	30	6
4-Nitrophenol	15	6
2-Nitropyrene	15	3
N-Nitrosodiphenylamine	15	3
HMX	15	N/D
Phenacetin	15	N/D
Phenanthrene	30	3
Phenol	15	N/D
Pyrene	45	N/D
1,2,4-Trichlorobenzene	N/A	3
2,4,6-Trinitrotoluene	15	N/D

Chemical	*# of Samples M1 Propellant*	*# of Samples M9 Propellant*
Metals:		
Aluminum	15	3
Cadmium	15	3
Calcium	15	3
Copper	15	3
Lead	15	3
Mercury	15	N/D
Potassium	15	3
Sodium	15	3
Titanium	15	3
Zinc	15	N/D
Other:		
HCl	1	1
HCN	4	N/A**
PM10	5	1

* N/D: Not Detected

** N/A: Not Applicable

2.4.3 Calculating the Chemical-Specific Emission Factor

An emission factor for each chemical for both propellants will be determined from the Bang Box emissions tests. In cases when more than one sample was analyzed, an overall emission factor for each chemical will be determined by averaging the emission factors calculated from each sample. If the sample was analyzed with more than one method, as is the case with some SVOCs, the higher average emission factor will be chosen. The emission factors contained in the emissions characterization report (MAANG, 1994) will be verified by recalculating the factors from the raw data found in the report. The report also includes data for unidentified VOCs and tentatively identified SVOCs. For the purposes of including the quantified amounts of the unidentified VOCs, the emission factors for the identified VOCs will be marked up by the appropriate percentage of unknown compounds. Some of the tentatively identified SVOCs (TICs) have been explained in the report as analytical contaminants or background constituents of the Bang Box. For the TICs that do not fall into one of those categories, the known SVOCs will be marked up by the appropriate percentage of quantified TICs. The explanation of the other TICs will be included in the final report.

2.5 Air Dispersion Modeling

The latest version of the Industrial Source Complex Short Term (ISCST3) model will be used to model emissions from the past propellant bag burning activities at Camp Edwards. This USEPA developed model is a steady-state Gaussian plume model which is capable of handling inputs of multiple sources, hourly meteorological data, and digitized terrain data. The model can estimate ambient concentration, dry deposition and wet deposition values for each source and receptor combination for each hour of meteorology data. The model assumes continuous operations but can calculate concentrations for a period as short as one hour.

2.5.1 Modeling Inputs

The ISCST3 model inputs that will be used to simulate the open burning of propellant at Camp Edwards are shown in Table 2-5. Each gun and mortar point where bag burning took place will be treated as a volume source. The following volume source inputs were determined using actual burn descriptions and recommendations in the ISC3 manual (USEPA, 1995): source height, initial horizontal dimension, and initial vertical dimension. Because the HHRA will be focusing on chronic risks, the model will be configured to return annual averages of ambient concentration, dry deposition rate, and wet deposition rate for each receptor. The gun points will be grouped together to determine the total concentrations and depositions from burning M1 propellant, and the mortar points will be grouped together to determine the total concentrations and depositions from burning M9 propellant.

Table 2-5. ISCST3 Model Inputs for Each Gun or Mortar Point

Parameter	*Input*
Source Type	Volume
Source Height	1.0 meter
Initial Horizontal Dimension (σ_{yo})	1.0 meter
Initial Vertical Dimension (σ_{zo})	2.0 meters
Plume Depletion Option	Wet and Dry
Terrain Option	Simple and Complex
Averaging Time	Annual
Urban/Rural Classification	Rural*
Emission Rate (unitized)	1 g/s
* The "Rural" classification will be confirmed with the appropriate land-use or population-based procedure in accordance with USEPA's Guideline on Air Quality Models (USEPA 1993).	

The model will be run in both particulate mode and vapor mode to simulate different chemical phases emitted from the burning. The chemical-specific emission factors will be multiplied by the appropriate particulate/vapor ratio before being multiplied by the following concentrations and depositions. For each receptor, the five emission categories to be calculated are particulate dry and wet deposition (P_{DD} and P_{WD}), particulate air concentration (P_C), vapor wet deposition (V_{WD}), and vapor air concentration (V_C). These concentration and deposition rates will be referred to as C/DRs throughout the rest of this protocol. Table 2-6 contains the USEPA default particulate and vapor mode input parameters that will be used to calculate the above emission categories. A list of the particulate/vapor ratios for each chemical will be included in the final report.

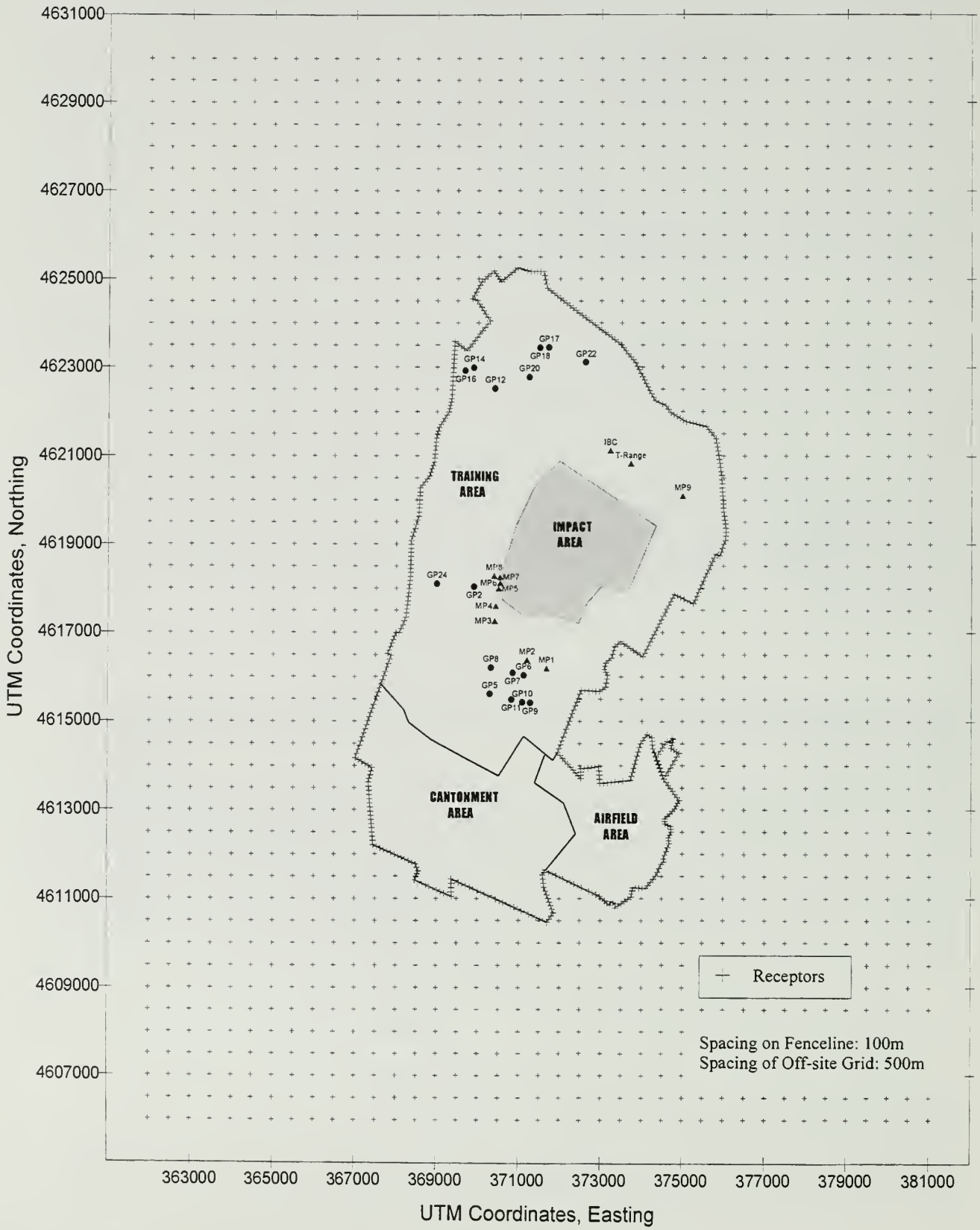
Table 2-6. Particle and Scavenging Coefficient Input Parameters

Input Parameter	*Value*	*Units*
Particle Density	1.0	g/cm^3
Array of Particle Sizes	1.0, 6.0, 15.0	µm
Fraction of Emissions in Each Particle Class	0.78, 0.19, 0.03	unitless
Particle Scavenging Coefficients for Liquid Precipitation	4.0E-05, 4.2E-04, 6.7E-04	hr/mm-s
Particle Scavenging Coefficients for Frozen Precipitation	1.3E-05, 1.4E-04, 2.2E-04	hr/mm-s
USEPA Liquid Vapor Scavenging Coefficient	1.7E-04	hr/mm-s
USEPA Frozen Vapor Scavenging Coefficient	5.7E-05	hr/mm-s

2.5.2 Receptors and Firing Points

The receptor array that will be modeled includes fenceline receptors, on-site discrete receptors, and an off-site Cartesian grid. The fenceline receptors will be placed at 100 m intervals along the entire installation fenceline. After the preliminary maximum is found at the fenceline, another model run will be executed with a tighter receptor grid placed around that point to determine the true maximum at that fenceline location within 25 meters. The discrete

Figure 2-1. Fenceline and Off-Site Cartesian Grid Receptor Locations



receptors will be placed at onsite residential housing areas, onsite schools, identified waterbodies and their respective watershed area, and various MMR worksites. The Cartesian receptor grid will be placed outside of the installation boundary covering at least 5 km from the boundary in all directions at 500 m spacing (see Figure 2-1). Digitized terrain data of the upper Cape Cod area will be utilized to give accurate terrain elevations of the receptors as well as the burn sites.

Tables 2-7 and 2-8 further describe the firing points and include the annual average of propellant burned for each site determined from the overall propellant burned and the average utilization of each firing point. The last column in each table contains the annualized burn rate of propellant which will be input into the model to determine annual C/DRs from each of the firing points.

Table 2-7. Gun Point Descriptions.

Gun Point	*UTM Coordinates Northing, Easting*	*Distance to Nearest Boundary (m)*	*Annual Average of Propellant Burned (lbs)*	*Annualized Burn Rate of Propellant (g/s)*
GP2	369910, 4618040	1560	0	0
GP5	370290, 4615620	2040	0	0
GP6	371120, 4616040	1450	738	1.06E-02
GP7	370850, 4616090	1725	619	8.91E-03
GP8	370320, 4616210	2250	330	4.75E-03
GP9	371280, 4615420	1050	495	7.12E-03
GP10	371090, 4615430	1225	428	6.16E-03
GP11	370820, 4615490	1500	294	4.23E-03
GP12	370410, 4622520	1025	108	1.56E-03
GP14	369900, 4622990	410	459	6.61E-03
GP16	369690, 4622920	300	382	5.49E-03
GP17	371720, 4623450	1025	93	1.34E-03
GP18	371500, 4623440	1150	165	2.37E-03
GP20	371240, 4622780	1550	578	8.31E-03
GP22	372630, 4623110	825	423	6.09E-03
GP24	369000, 4618110	660	41	5.94E-04

Table 2-8. Mortar Point Descriptions.

Mortar Point	*UTM Coordinates Northing, Easting*	*Distance to Nearest Boundary (m)*	*Annual Average of Propellant Burned (lbs)*	*Annualized Burn Rate of Propellant (g/s)*
MP1	371690, 4616190	975	97	1.40E-03
MP2	371200, 4616380	1475	73	1.04E-03
MP3	370410, 4617260	2150	181	2.60E-03
MP4	370430, 4617600	2160	120	1.72E-03
MP5	370500, 4617990	2175	21	3.03E-04
MP6	370540, 4618120	2200	83	1.20E-03
MP7	370530, 4618250	2160	68	9.81E-04
MP8	370390, 4618280	2025	70	1.01E-03
MP9	375000, 4620090	1000	0	0.00E+00
IBC	373230, 4621120	1600	4	5.22E-05
T-Range	373720, 4620820	1540	7	1.04E-04

2.5.3 Calculating Chemical-Specific Emission Rates from the Firing Points

In order to calculate a chemical-specific emission rate from each of the mortar and gun points, the annual burn rate for each site will be entered into the model in grams/second. The model will treat the burning activity as though it happened continuously throughout the year although the actual burning occurred on about 75 days per year and 5 nights per year. The modeling results will be less affected by this approach because the model will be calculating annual averages for concentrations and depositions. In fact, this approach will be conservative by including the nighttime met conditions that return less dispersion (and therefore higher C/DRs).

There will be two separate model runs for the gun points and mortar points. The M1 propellant burns will be modeled from each of the gun points and the M9 propellant burns will be modeled from each of the mortar points. For the M1 propellant model run, the gun points will be grouped together so that the contribution from each site will be added to result in an overall C/DR at each receptor. The same methodology will apply for the M9 propellant model run except that the mortar points will be grouped together. The scenario-appropriate concentration and deposition rate (defined in the next section) for both the mortar and gun points will be multiplied by the array of emission factors to come up with chemical-specific emission rates.

2.6 Selection of Scenario Specific Concentration and Deposition Rates

The goal of the chronic modeling effort is to estimate concentrations and depositions that are as realistic as possible without underestimating risks. The C/DRs determined from the ISCST3 model will be averaged for all modeled years at each receptor location. This will result in a long-term or chronic estimate of average C/DRs at each receptor location.

As described in Table 2-9, the appropriate concentration and deposition rate for each of the scenarios to be evaluated will be used to determine exposures and chronic health risks. All of the offsite scenarios will be evaluated using the maximum C/DR that occurs at the fenceline. The on-site scenarios (including schools, worksites, and housing areas) will have a specific receptor (or small receptor grid) placed at their location. The maximum C/DR for all of the on-site schools will be used to evaluate the on-site student, the maximum C/DR for all of the MMR cantonment worksites will be used to evaluate the on-site worker, and the maximum C/DR found in the housing areas will be used to evaluate the on-site resident. The recreational fisher and recreational swimmer scenarios will be evaluated using a receptor grid that covers the specific waterbody and watershed area. The average C/DR in the specific watershed area and waterbody will be used to evaluate the fishers and swimmers (both on- and off-site). The recreational gardener will be evaluated by the maximum C/DR that occurs either at the on-site housing areas or the fenceline, whichever is greater.

Table 2-9. Scenario Specific Concentration and Deposition Rates

Scenario	*Receptor Description*	*How Evaluated*
Off-site Resident	Fenceline	Maximum
Off-site Worker	Fenceline	Maximum
Off-site Student	Fenceline	Maximum
On-site Resident	Discrete	Maximum
On-site Worker	Discrete	Maximum
On-site Student	Discrete	Maximum
Recreational Fisher	Grid	Average
Recreational Swimmer	Grid	Average
Recreational Gardener	Discrete/Fenceline	Maximum

3.0 HUMAN HEALTH RISK ASSESSMENT

3.1 Definition of Study Area

The study area chosen for this risk assessment will be those areas determined to have the worst-case exposure to the chemicals evaluated. These areas will be determined by air modeling as described in Section 2.0.

3.2 Selection of the Chemicals of Concern

The list of compounds that will be evaluated in the HHRA will be referred to as the Chemicals of Concern (COCs). The COCs will be chosen from the list of compounds emitted from the bag burning process as described in Section 1.4 and 2.0. For the direct inhalation analysis, all compounds emitted will be retained as COCs.

For the indirect analyses, a compound found in the Bang Box testing will be considered a COC if the IG recommends it, if the compound exhibits a tendency to partition to fatty tissues in plants and animals (i.e., the octanol-water partition coefficient, log K_{ow}, is greater than 3.0), or if it is toxic relative to the other COCs (i.e., it has a cancer slope factor greater than 0.1 or a reference dose of less than 0.09). As per the IG, the only exception is that the indirect exposure evaluation will not include any VOCs.

3.3 Identification of Potentially Exposed Populations

A sub-population is defined as a group of individuals who exhibit similar behavior and activity patterns. The similar behavior and activity patterns allow assignment of a similar combination of exposure factors. The HHRA will consider the following sub-populations because they represent both the most probable and most susceptible sub-populations within the study area:

- Adult on-post resident who works on-post, consumes vegetables from a home garden, and consumes fish caught recreationally
- Adult on-post resident who works off-post, consumes vegetables from a home garden, and consumes fish caught recreationally
- Adult off-post resident who works on-post, consumes vegetables from a home garden, and consumes fish caught recreationally

- Adult off-post resident who works off-post, consumes vegetables from a home garden, and consumes fish caught recreationally

- Child on-post resident who attends school on-post, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

- Child on-post resident who attends school off-post, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

- Child off-post resident who attends school on-post, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

- Child off-post resident who attends school off-post, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

3.4 Identification of Exposure Pathways

A chemical only poses a health hazard if a complete exposure pathway exists that links the chemical of concern to a human population or to an individual. A complete exposure pathway, as defined by Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (RAGS) consists of four essential elements:

- A source and mechanism of substance release

- A receiving or transport medium (air, ground water, surface water, sediment, or soil)

- A point of potential human contact with the substances ("exposure point")

- An "exposure route" such as eating and drinking (ingestion) or breathing (inhalation)

If one or more of the above elements are missing, the pathway is incomplete and no risk exists. The potentially complete pathways that will be investigated in this HHRA are inhalation and ingestion. Specific inhalation and ingestion routes are described below.

3.4.1 Direct Inhalation

Direct inhalation of emissions from the propellant bag burning will be evaluated for chronic noncarcinogenic effects and carcinogenic effects for each of the sub-populations listed in Section 3.3.

3.4.2 Soil and Dust Ingestion

Individuals working or playing outdoors may be exposed to emissions that have deposited on or permeated into the surface soil. Individuals may also be exposed to indoor dust that had its origins outdoors. Children are particularly sensitive to soil exposure pathways as they spend significant periods of time outdoors. Incidental ingestion of soil will be evaluated for all sub-populations listed in Section 3.3.

3.4.3 Surface Water Ingestion

Propellant bag burning emissions may enter bodies of water in the vicinity of MMR through direct deposition onto the waterbody or through runoff of impacted soil that enters the waterbody. An individual could be exposed to potentially contaminated water during recreational swimming by accidental ingestion of water. This route of exposure will be evaluated for all child sub-populations listed in Section 3.3, as they are both the most likely to swim in local waterbodies, and the most susceptible.

3.4.4 Food Chain

Propellant bag burning emissions may enter the food chain from various sources. Constituents may enter plant tissues from air-to-plant transfer, through absorption from substances directly deposited on the leaves, and by root uptake. The constituents absorbed by these plants may, in turn, be consumed directly by local residents who maintain gardens for recreational purposes.

Propellant bag burning combustion products dissolved in the surface water and adsorbed to underwater sediments may be assimilated in the tissues of fish in local waterbodies. Fish that are consumed by local recreational fishers from these waterbodies may expose individuals to additional risk.

Food grown in home gardens, and fish caught by recreational fishers will be considered for all the sub-populations described in Section 3.3.

3.5 Exposure Assessment Components

An exposure assessment involves defining the study area; identifying exposed individuals, identifying how an individual contacts a substance (exposure pathway); determining the concentration of each substance in air, soil, surface water, sediments, and foods; and estimating the amount of substance to which each individual is exposed (intake or dose). Paragraphs 3.1 through 3.4 address four of these components, namely definition of the study area; selection of COCs; identification of exposed sub-populations; and identification of

exposure pathways. The following sections will address the remaining exposure assessment components.

3.5.1 Estimating Exposures and Intakes in Exposed Populations

To quantitatively assess the potential exposures associated with the direct (inhalation) and indirect (ingestion) exposure routes, daily intakes are determined. The equations that will be used to provide estimations of the daily intakes are presented below and in Appendix B.

3.5.1.1 Inhalation of Air

This exposure pathway involves the inhalation of volatile substances from the air or the inhalation of suspended particulate in the air that are substance-bearing. For assessment of cancer risk, an inhalation intake rate must be developed. Equation 1 is used to develop the inhalation intake for the cancer assessment. The variable values are given in Appendix B. For the chronic noncancer assessment, the respirable concentration in the air as modeled is used to calculate the hazard. Therefore, inhalation intake for chronic noncancer is not calculated.

Equation 1: Inhalation Intake for Carcinogenic Risk Assessment

$$LADI = \frac{CA \times IR \times ET \times EF \times ED}{BW \times LT}$$

LADI	=	lifetime average daily intake, mg/kg-day (carcinogenic substances)
CA	=	respirable concentration of substance in air, mg/m^3
IR	=	inhalation rate, m^3/hr
ET	=	exposure time, hr/day
EF	=	exposure frequency, days/yr
ED	=	exposure duration, yr
BW	=	body weight, kg
LT	=	number of days in a lifetime, days

3.5.1.2 Soil Ingestion

This exposure route requires direct contact with soil upon which emissions from the propellant bag burning have been deposited. The contact may be via the hands or lips, followed by inadvertent hand-to-mouth contact or licking of lips. The intake equations for substances with carcinogenic (see Equation 2) and noncarcinogenic (see Equation 3) health effects are presented

below. Equations for calculating COC concentrations in soil are given in Section 3.5.2.2. The variable values are given in Appendix B.

Equation 2: Soil Ingestion Intake for Carcinogenic Risk Assessment:

$$LADI = \frac{CS \times IR \times CF \times EF \times ED}{BW \times LT}$$

LADI	=	lifetime average daily intake, mg/kg-day
Cs_a	=	time averaged concentration of substance in soil, mg/kg
IR	=	ingestion rate, mg/day
CF	=	conversion factor, 1E-06 kg/mg
EF	=	exposure frequency, days/yr
ED	=	exposure duration, yr
BW	=	body weight, kg
LT	=	number of days in a lifetime, days

Equation 3: Soil Ingestion Intake for Chronic Noncancer Risk Assessment:

$$MDI = CS_m \times IR \times CF$$

MDI	=	maximum daily intake, mg/day
CS_m	=	maximum concentration of substance in soil, mg/kg
IR	=	ingestion rate, mg/day
CF	=	conversion factor, 1E-06 kg/mg

3.5.1.3 Ingestion of Vegetables from Home Garden

The ingestion intake equations for plants grown in home gardens are presented below. Equation 4 is for intakes used in calculating carcinogenic risks and Equation 5 is for intakes used in calculating chronic noncancer hazards. An intake will be estimated for each vegetation category, including mature leafy vegetables, aboveground protected vegetation, aboveground exposed round vegetation, aboveground exposed long vegetation, and root vegetation. Equations for calculating the concentrations of COCs in plants are given in Section 3.5.2.4. The variable values are given in Appendix B.

Equation 4: Vegetable Ingestion Intake for Carcinogenic Risk Assessment:

$$LADI = \frac{P_{ia} \times IR \times CF \times FI \times EF \times ED}{BW \times LT}$$

$LADI_i$	=	lifetime average daily intake of i^{th} plant group, mg-kg-day
P_{ia}	=	time averaged concentration of substance in i^{th} plant group, mg/kg
IR	=	ingestion rate, g/day
CF	=	conversion factor, 1E-03 kg/g
FI	=	fraction of produce from local source, unitless
EF	=	exposure frequency, days/yr
ED	=	exposure duration, yr
BW	=	body weight, kg
LT	=	number of days in a lifetime, days

Equation 5: Vegetable Ingestion Intake for Chronic Noncancer Risk Assessment:

$$MDI_i = P_{im} \times IR \times CF \times FI$$

MDI_i	=	maximum daily intake of i^{th} plant group, mg/day
P_{im}	=	maximum concentration of substance in i^{th} plant group, mg/kg
IR	=	ingestion rate, g/day
CF	=	conversion factor, 1E-03 kg/g
FI	=	fraction of produce from local source, unitless

3.5.1.4 Ingestion of Locally-Caught Fish

This exposure route requires consumption of locally-caught fish that have been exposed to propellant bag burning emissions deposited in lakes and ponds. The intake equations for substances with carcinogenic and noncarcinogenic health effects are presented below. Other pertinent equations and parameters are in Appendix B.

Equation 6: Fish Ingestion Intake for Carcinogenic Risk Assessment:

$$LADI = \frac{CC_a \times IR \times CF \times FI \times EF \times ED}{BW \times LT}$$

LADI	=	lifetime average daily intake, mg/kg-day
CC_a	=	time averaged concentration of substance in fish, mg/kg
IR	=	ingestion rate, g/day
CF	=	conversion factor, 1E-03 kg/g
FI	=	fraction of fish ingested that are caught locally, unitless
EF	=	exposure frequency, days/yr
ED	=	exposure duration, yr
BW	=	body weight, kg
LT	=	number of days in a lifetime, days

Equation 7: Fish Ingestion Intake for Chronic Noncancer Risk Assessment:

$$MDI = CC_m \times IR \times CF \times FI$$

MDI	=	maximum daily intake, mg/day
CC_m	=	maximum concentration of substance in fish, mg/kg
IR	=	ingestion rate, g/day
CF	=	conversion factor, 1E-03 kg/g
FI	=	fraction of fish ingested that are caught locally, unitless

3.5.1.5 Incidental Ingestion of Water While Swimming

This exposure route requires incidental ingestion of surface water into which propellant bag burning emissions have been deposited. Ingestion may occur during swimming or other recreational water activities. The intake equations for substances with carcinogenic and noncarcinogenic health effects are presented below:

Equation 8: Incidental Water Ingestion Intake for Carcinogenic Risk Assessment:

$$LADI = \frac{CW_a \times CR \times ET \times EF \times ED}{BW \times LT}$$

LADI	=	lifetime average daily intake, mg/kg-day
CW_a	=	time averaged concentration of substance in water, mg/L
CR	=	contact rate, L/hr
ET	=	exposure time, hr/day
EF	=	exposure frequency, day/yr
ED	=	exposure duration, yr
BW	=	body weight, kg
LT	=	number of days in a lifetime, days

Equation 9: Incidental Water Ingestion Intake for Chronic Noncancer Risk Assessment:

$$MDI = CW_m \times CR \times ET$$

MDI	=	maximum daily intake, mg/day
CW_m	=	maximum concentration of substance in water, mg/L
CR	=	contact rate, L/hr
ET	=	exposure time, hr/day

3.5.2 Determination of Media Concentrations

Fate and transport models that simulate the dispersion of open burning emissions in the environment will be used to estimate the exposure concentrations in air, soil, sediments, surface water, and food. These models are based on USEPA's 1990 IED and the 1993 IEDA. The changes recommended in the IEDA will be implemented when different from the IED.

3.5.2.1 Estimation of Air Concentrations

The methodology used to develop air concentrations is described in Section 2.0 of this protocol.

3.5.2.2 Estimation of Soil Concentrations

Soil concentrations are required to estimate the uptake of substances from the soil by vegetation, and to determine the amount of a chemical that may have been inadvertently ingested with soil. Equation 10 will be used to estimate the soil concentrations for the carcinogenic COCs. Equation 11 will be used to estimate the soil concentrations for the noncarcinogenic COCs (USEPA, 1994a).

Soil concentrations will be estimated for both surface soils [1 centimeter (cm)] and for root zone soils (20 cm), assuming complete mixing with the soil layer of interest. The surface soil concentrations will be used in incidental ingestion exposure pathways. The root zone concentrations will be used in plant uptake equations.

All parameter definitions and default values required to determine the soil concentration are provided in Appendix B.

Equation 10: Soil Concentration for Carcinogenic Risk Assessment:

$$CS = \frac{Sc_1 \times (T_c - T_1) + Sc_2 \times (T_2 - T_c) \times CF}{T_2 - T_1}$$

CS	=	substance concentration in soil, mg/kg
Sc_1	=	average soil concentration over the period of deposition, dimensionless
Sc_2	=	average soil concentration over the period after deposition, dimensionless
T_c	=	total time of deposition, yr
T_1	=	time before deposition, yr
T_2	=	total exposure time period, yr
CF	=	units conversion factor, 1E+06 mg/kg

Equation 11: Soil Concentration for Chronic Noncancer Risk Assessment:

$$CS = \frac{D_s \times [1 - \exp(-ks \times T_c)]}{ks}$$

CS = substance concentration in soil, mg/kg
Ds = deposition term, mg/kg-yr
ks = soil loss constant due to all processes, yr^{-1}
Tc = total time of deposition, yr

3.5.2.3 Estimation of Surface Water and Sediment Concentrations

To determine the amount of a chemical of concern that may have been accidentally ingested while swimming in a waterbody or from consuming fish caught in the waterbody, the amount of the substance in the waterbody and its sediment must be determined.

Surface waterbodies may receive substances from deposition and from the runoff over impacted soils in the vicinity of the propellant bag burning. Eroded soils are carried into the surface water with the runoff. The concentration of constituents in the surface water is required to estimate exposure through surface water ingestion and to estimate the uptake of substances from the surface water by fish and other animals.

The USEPA presented a model to estimate constituent concentrations in surface waterbodies and associated sediments in the 1990 IED. A USEPA working group reviewed this document and recommended an alternate algorithm to estimate surface water and sediment concentrations. The alternate algorithm is presented in the 1993 IEDA. The assumptions contained in this algorithm include the following:

- soil concentrations within a depositional area of a watershed are uniform;
- substances enter into a surface waterbody via soil erosion, dissolved substances in annual surface runoff, deposition, and diffusion of vapor phase constituents; and,
- steady state is achieved between concentrations in the dissolved phase in the water column, concentrations in the sorbed phase in the water column, and concentrations in bottom sediments.

To determine surface water and sediment concentrations, the load to the surface waterbody from various sources must be estimated. These sources include the load from soil

erosion, the load from surface runoff, the load from direct deposition, and the load from diffusion. The equations that will be used to estimate the various loads to surface waters will be taken directly from the revised section 9.2 1993 IEDA, the 1994 IG, the 1994 Errata Sheet, and the 1994 Soil Averaging Addendum. The equations and variable explanations are in Appendix B.

3.5.2.4 Estimation of Vegetation Concentrations

The concentrations of substances in vegetation is required to estimate the human exposure through ingestion of food grown in a home garden. In the HHRA, the concentrations of the COCs will be estimated for the following vegetation categories:

- leafy vegetables (mlv) (lettuce, cabbage, broccoli, cauliflower);
- aboveground protected vegetation (agp) (sweet corn, shell peas, lima beans, soybeans, cantaloupes, watermelons, pumpkins, oranges);
- aboveground exposed round vegetation (ager) (tomatoes, strawberries, peaches, apples, cherries, blueberries, pears, apricots, nectarines);
- aboveground exposed long vegetation (agel) (string beans, squash, cucumbers, asparagus, rhubarb); and,
- root vegetation (bg) (potatoes, yams, carrots, peanuts, onions, beets).

Uptake of constituents from the air into above-ground plants can occur through three mechanisms: uptake by roots, direct deposition on exposed plant tissues, and air-to-plant transfer of vapor-phase substances. Below-ground plant uptake occurs through uptake by roots alone.

Equation 12: Total Concentration of Substance in an Above-Ground Plant Group

$$P = \mathrm{Pr} + Pd + Pv$$

P	=	total concentration of substance in an above-ground plant group, mg/kg
$\mathrm{Pr}_{(ag)}$	=	concentration of substance in an above-ground plant group due to root uptake, mg/kg
Pd	=	concentration of substance in an above-ground plant group due to direct deposition, mg/kg
Pv	=	concentration of substance in an above-ground plant group due to air-to-plant transfer, mg/kg

Equation 13: Total Concentration of a Substance in a Below-Ground Plant Group

$$Pr_{bg} = \frac{CS \times RCF \times VG_{bg}}{K_{ds}}$$

Pr_{bg}	=	concentration in below-ground plant parts due to root uptake, mg/kg
CS	=	soil concentration, mg/kg (see Equations 10 and 11, for carcinogenic and chronic noncancer risk assessment, respectively)
RCF	=	ratio of concentration in roots to concentration in soil pore water, (mg substance/kg plant tissue FW)/(μg substance/mL pore water)
VG_{bg}	=	below-ground vegetable correction factor, unitless
K_{ds}	=	soil-water partition coefficient, cm^3/g or mL/g

Appendix B includes all other parameter definitions and default values required to determine the concentration of COCs in vegetation.

3.5.2.5 Estimation of Fish Concentrations

Emissions from propellant bag burning may enter local surface waterbodies through several means, including diffusion of the vapor phase, deposition of particle-bound substances from the plume to the surface waterbody, and deposition onto watershed soils, followed by runoff and transport into surface waterbodies . These emissions may be incorporated into fish living in the waterbody. The concentration of constituents in fish is required to estimate human exposure via ingestion. The 1990 IED and the 1993 IEDA discuss several methods for determining concentrations of substances in fish. The method most appropriate for the COCs will be used:

- For certain lipophilic compounds described in USEPA's *Water Quality Guidance for the Great Lakes Systems* (USEPA 1993c), bioaccumulation factors (BAFs) will be used to obtain lipid-based fish concentrations. The BAF multiplied by the total water column concentration gives a lipid-based fish tissue concentration.

- For substances that have been validated for the Food and Gill Exchange of Toxic Substances (FGETS) Model, this model will be used.

- For other substances, the Bioconcentration Factor (BCF) will be obtained from

Superfund Public Health Evaluation Manual (USEPA, 1986), scientific literature and databases, or calculated from the K_{ow}. These will be adjusted for lipid content of dietary seafood versus experimental organisms. The concentration of contaminant in fish is calculated as shown in Equation 14. All other equations, parameters and variables are in Appendix B.

Equation 14: Concentration of Substance in Fish

$$C_{fish} = \frac{C_{Sb} \times f_{lipid} \times BSAF}{OC_{sed}}$$

C_{fish}	=	concentration in fish, mg/kg
C_{sb}	=	concentration sorbed to bed sediments, mg/kg
f_{lipid}	=	fish lipid content, unitless
BSAF	=	biota to sediment accumulation factor, unitless
Oc_{sed}	=	fraction organic carbon in bottom sediment, unitless

3.6 Toxicity Assessment

Hazard identification and dose-response evaluations are two major components of the toxicity evaluation phase of the HHRA.

3.6.1 Hazard Identification

In hazard identification, an attempt is made to identify the type of toxic effect produced by a substance and the exposure conditions associated with that effect. All substances are toxic at some dose and exposure duration. In the risk assessment, the chronic toxicity of the COCs will be determined for the inhalation and ingestion routes of exposure.

A number of the COCs have been identified as possible, probable, or known human carcinogens. Carcinogenic effects will be assessed separately from other chronic systemic effects.

3.6.2 Dose-Response Evaluation

Dose-response evaluation is the process of characterizing and quantifying the degree of toxic effects in terms of the exposure doses. The numerical expression of chronic and sub-

chronic dose-response information is typically the Cancer Slope Risk Factor (CSF) or Unit Risk (UR) for carcinogenic effects and the Reference Dose (RfD) or Reference Concentration (RfC) for chronic, systemic or noncarcinogenic effects. The RfC applies to lung or systemic hazards for inhalation exposures.

3.6.2.1 Slope Factors and Unit Risks

The CSFs are determined by estimating the slope of the dose-response function for each COC. When sufficient human data are available, the value that best estimates the slope is used. When risk estimates are based on data from experimental animals, the toxicity value generated is an estimate of the 95th percentile upper confidence limit on the slope. In other words, the CSF is a plausible upper-bound estimate of the probability of developing cancer as a result of exposure to a unit concentration of a particular carcinogen over a lifetime (USEPA, 1989b).

Toxicity values for carcinogenic effects can also be expressed in terms of risk per unit concentration of the substance in the medium where human contact occurs. These measures, called URs, are calculated by dividing the slope factor by 70 kg (the default adult body weight) and multiplying by the inhalation rate (20 m^3/day) for risk associated with unit concentration in air. The standardized duration for unit risks is understood to be a continuous lifetime exposure. In the event the toxicity value of a COC is provided as a unit risk, the unit risk will be used to derive the CSF.

3.6.2.2 Reference Doses and Reference Concentrations

Estimates of noncarcinogenic toxicity are based on the assumption that toxic effects will only occur after exposure exceeds some threshold level. The toxicity values derived are called RfDs (or RfCs for inhalation values). There are two types of RfDs and RfCs: chronic and subchronic. The chronic RfD (or RfC) represents an estimate of a daily exposure level for the human population, including sensitive sub-populations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specifically developed to be protective for exposures to a substance which are longer than seven years (Hull and Suter, 1994). Subchronic RfDs (or RfCs) represent an estimate of a daily exposure level for the human population, including sensitive sub-populations, that is likely to be without an appreciable risk of deleterious effects for exposures from fourteen days to seven years.

The RfD and RfC values are estimated by dividing either the highest dose of the substance that did not produce a toxic effect in experimental studies [No Observed Adverse Effect Level (NOAEL)], or the lowest dose that did produce a toxic effect [Lowest Observed Adverse Effect Level (LOAEL)] by the product of Uncertainty Factors (UFs) and a Modifying Factor (MF). The UFs account for:

- variation in general population
- extrapolation from animal data to humans
- extrapolation from a subchronic study to derive a chronic RfD (or RfC)
- use of a LOAEL when a NOAEL is not available
- situations when the available data do not adequately address all possible adverse outcomes in humans

The MF indicates the confidence in the quality of the data for predicting human hazard.

3.7 Toxicity Data Sources

In the HHRA, the relevant toxicity values will be taken from the latest update of the USEPA Integrated Risk Information System (IRIS). Verified toxicity values are not always available. Other reliable sources, such as Health Effects Assessment Summary Tables (HEAST) will be used to compile toxicity data for some of the chemicals of concern. In addition, the USEPA Environmental Criteria and Assessment Office (ECAO) and Superfund Health Risk Technical Support Center (TSC) will be consulted. The toxicity value and the source of the value will be specified.

3.8 Known Toxic Substances Requiring Special Handling

Several of the COCs require a different toxicity assessment than the methodology outlined previously. Some of these substances have known toxic effects, but limited or no toxicity values. In other cases, the substances may speciate in the environment into forms which are considered more toxic. The substances requiring a special toxicity assessment include: lead, mercury, chromium, acid gases and particulate matter.

3.8.1 Lead

The USEPA currently does not list any toxicity data for lead, even though it is classified as a B2 carcinogen, and it has known non-carcinogenic effects. They have instead developed an uptake/biokinetic modeling approach for evaluating the risks posed by exposures to lead. The Integrated Exposure Uptake Biokinetic Model (IEUBK) predicts potential blood lead levels for children from 0 to 84 months (USEPA, 1994c). Children are generally more susceptible to lead exposures than adults due to higher soil ingestion rates, greater absorption from the gut, and more critical toxic effects. In the evaluation, environmental concentrations of lead resulting from

open burning emissions will be used with the latest version of the biokinetic model to predict the child blood lead levels for the sub-populations evaluated.

3.8.2 Mercury

Mercury can exist in either organic or inorganic forms in the environment. Mercury emissions from the open burning are expected to be in an inorganic form. It is possible, however, that the mercury will be converted to its more toxic organic form. The extent of such conversion will be evaluated in the HHRA. If it is determined that organic forms could occur, these exposures will be assessed using chronic toxicity data for organic mercury, if available. In either case, the rationale for selecting the toxicity data will be provided.

3.9 Risk Characterization

Once the toxicological information (e.g., CSFs, URs, RfDs) is known about each of the chemicals of concern, the health risk to each sub-population will be determined. This will be accomplished in several steps

3.9.1 Estimation of Carcinogenic Risks

Risk estimates for carcinogenic compounds are generally expressed as an excess upper-bound probability (e.g., 1E-06) that an individual in a population will develop cancer as a result of exposure to the substance. These risks are termed excess lifetime cancer risks (ELCR). An excess lifetime cancer risk of 1E-06 indicates that an individual has a chance of developing cancer from exposure to the carcinogenic substance somewhere in the range from zero to one in one million. The USEPA states that to ensure the protection of human health, the total incremental risk from the high-end individual exposure to carcinogenic constituents should not exceed 1E-05 (USEPA, 1994d); consequently a risk of 1E-05 or less will be considered below the level of concern in the HHRA .

In cases of multiple substance exposures, such as the one in this HHRA, the cancer risks for each individual constituent will be summed to obtain an exposure pathway total. In addition, the risk estimates will be summed across exposure pathways, but only for those exposure pathways to which the individual in a sub-population is subjected. The following equation will be used to estimate cancer risk:

Equation 15: For Oral and Inhalation Cancer Risks for Substances with a CSF:

$$Risk_K = LADI_K \times CSF_K$$

$Risk_K$ = the excess lifetime probability of developing cancer due to the exposure to open burning emission k, unitless
$LADI_K$ = lifetime average daily intake of substance k, mg/kg-day
CSF_K = carcinogenic slope factor for substance k, $(mg/kg\text{-}day)^{-1}$

3.9.2 Estimation of Chronic Noncarcinogenic Hazards

The estimation of cancer risk is based on an incremental probability of developing cancer. This assumes that there is no threshold for a carcinogens effect. To estimate the noncarcinogenic hazard, it is presumed that there is a threshold for effect. That is, the noncancer hazard quotient assumes that there is a level of exposure below which it is unlikely for even sensitive populations to experience adverse health effects. If the exposure exceeds this threshold, there may be concern for potential noncancer effects (USEPA, 1989b). The equations used to determine the noncarcinogenic hazards (hazard quotients) (HQ) are as follows:

Equation 16: For Noncancer Inhalation Exposures:

$$HQ_{inh} = CA/RfC$$

HQ_{inh} = inhalation hazard quotient for substance, unitless
CA = concentration of substance in air, mg/m^3
RfC = reference concentration, mg/m^3

Equation 17: For Noncancer Oral Exposures:

$$HQ_i = \frac{MDI_i}{BW \times RfD_i}$$

HQ_i = hazard quotient for substance i, unitless
MDI_i = maximum daily intake of substance i, mg/day
RfD_i = reference dose for substance , mg/kg/day

Chronic RfDs are used with exposures lasting greater than seven years. Some of the exposure scenarios, however, may model exposures for less than this time, e.g., the child scenarios. Subchronic RfDs and RfCs would be preferable for these exposures; and will be used, if available. If subchronic RfDs and RfCs are not available, the more conservative chronic value will be used.

As a screening measure, the HQ values for individual substances associated with a given exposure pathway will be summed. This summation is referred to as the hazard index (HI). Derivation of an HI by summing all substances for a given exposure pathway is not entirely appropriate because different substances have different effects and mechanisms of action on a target organ or system. In addition, the cumulative effects of substances may be antagonistic or synergistic. As recommended by the USEPA, if an HI greater than the health standard is calculated, the substances will be segregated by effect and by mechanism of action prior to summation.

The calculation of HI values should take into account background exposures not associated with propellant bag burning emissions. To account for background exposures the emissions may only contribute 25% of the noncarcinogenic health standard, which in most cases is one (or unity) (USEPA, 1994d). Consequently, in the HHRA a HI of 0.25 or less will be considered below the threshold of concern.

3.10 Uncertainty Analysis

Uncertainty analysis summarizes how variability and uncertainty may affect the numbers estimated in a risk assessment and the conclusions drawn. The dose-response evaluation (toxicity assessment) and the exposure assessment are the primary sources of uncertainty in any risk assessment.

3.10.1 Uncertainty Associated with the Toxicity Assessment

A majority of the uncertainties in the toxicity assessment include limited data for many of the COCs, extrapolations from animal studies to assign human values, extrapolations from high dose studies for low dose exposures, and limited knowledge regarding synergistic or antagonistic effects of substance combinations.

To account for these uncertainties, MFs are applied to the non-cancer reference values to ensure they are extremely conservative; consequently, the risks and hazard are generally overestimated.

3.10.2 Uncertainty Associated with the Exposure Assessment

In general, three types of uncertainty are associated with the exposure assessment: scenario uncertainty, parameter uncertainty, and model uncertainty.

3.10.2.1 Scenario Uncertainty

Scenario uncertainty occurs due to the absence of information associated with exposure and intakes. Sources of scenario uncertainty include errors in descriptive information; aggregation errors (e.g., assuming all individuals are the same); inaccurate professional judgment; and incomplete analysis (e.g., failure to consider all exposed sub-populations and major routes of exposure).

Scenario uncertainty is generally not quantifiable, and often unavoidable, although errors may significantly impact the estimated risks. Detailed discussions will be included within the risk assessment that describe why each particular scenario was selected and the sources of possible uncertainties associated with each scenario. The impact of possible scenario uncertainties will be assigned a qualitative measurement, such as high, medium, or low. In addition, scenario uncertainty will be minimized by utilizing site-specific data and information when recommended by the guidance.

3.10.2.2. Parameter Uncertainty

Types of parameter uncertainty include measurement errors, sampling errors, variability, and the use of generic or surrogate data. Two different categories of parameters are subject to parameter uncertainty. These categories include exposure parameters and fate and transport parameters. Exposure parameters are used in the exposure assessment to represent the behavior and activity pattern of the individuals. Fate and transport parameters are used in the exposure assessment to estimate substance concentrations in the various media and foods at various locations.

Exposure parameters and fate and transport parameters may be determined from site-specific data and survey information, or from generic or surrogate sources such as nationwide surveys and published literature. The magnitude of the error associated with each parameter is determined largely by the information used in assigning the parameter value.

3.10.2.3. Model Uncertainty

Many models and algorithms will be used in the screening assessment to predict emissions, media concentrations, and intakes. Models and algorithms, however, are subject to considerable uncertainty. For this reason, most models are designed to predict very conservative

or "high end" estimates. Quantification of model uncertainty is generally not possible. Detailed discussions will be included within the risk assessment that describe the sources of possible uncertainties associated with each scenario.

3.11 Recommendations

Review this protocol and provide comments and/or recommendations by 8 September, 1997 to:

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ATTN: MCHB-DC-HER (CPT Deborah Hastings)
5158 Blackhawk Road, Bldg 1677
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Mr. Don Consolmagno, MMR, Public Affairs Officer, Bldg 1204 can be reached for questions during the comment period at (508) 968-5824.

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Appendix A

References

1. Agency for Toxic Substances and Disease Registry. 1994. *Otis Air National Guard Base/Camp Edwards Falmouth, Barnstable County, Massachusetts, CERCLIS No. M 2570024487, January 25, 1994.* National Technical Information Service, Springfield, VA.

2. Department of Environmental Protection, Commonwealth of Massachusetts. 1994. *Draft "Terms of Reference for Preparing a Risk Assessment Evaluating Propellant Bag-Burning at Camp Edwards.* Commonwealth of Massachusetts Executive Office of Environmental Affairs. Boston, Massachusetts.

3. Maryland Army National Guard (MAANG). 1994. *Characterization of Emissions Resulting from Thermal Treatment of Selected Propellants: A Dugway Proving Ground Bang Box Study, Massachusetts Army National Guard, 18 November 1993.*

4. Suter II, G.W. 1996. *Toxicological benchmarks for screening contaminants of potential concern of effects on freshwater biota.* Environ Toxicol Chem 15(7):1232-1241.

5. US Army Environmental Hygiene Agency. 1987. *Investigation of Soil Contamination from Propellant Burns No. 37-26-1065-87, Camp Edwards, Massachusetts,11 September, 1987.*

6. US Army Environmental Hygiene Agency. 1991. *Health Risk Assessment Concerning Open Burning of Gun Propellants, No. 65-32-0716-91, Camp Edwards, Massachusetts, 17 May 1991.*

7. US Army Environmental Hygiene Agency. 1993. *Air Quality Assessment, Test Design Plan for Camp Edwards Propellant Burning Bang Box Facility, No. 43-21-N700-93,Dugway Proving Ground, Utah, 15-18 March 1993.*

8. USEPA. 1986. *Superfund Public Health Evaluation Manual.* Office of Emergency and Remedial Response and Office of Solid Waste and Emergency Response. EPA/540/1-86/060.

9. USEPA. 1989a. *Exposure Factors Handbook.* Final Report. Office of Health and Environmental Assessment. EPA/600/8-89/043.

10. USEPA. 1989b. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A).* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002.

11. USEPA. 1990. *Methodology for Assessing Health Risk Associated with Indirect Exposure to Combustor Emissions.* Interim Final. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development. EPA/600/6-90/003. Cincinnati, Ohio.

12. USEPA. 1992. *Guidelines for Exposure Assessment.* Final Draft. Office of Health and Environmental Assessment.

13. USEPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, DC EPA/600/AP-93/003.

14. USEPA. 1993b. *Appendix A: USEPA's Guideline on Air Quality Models.*

15. USEPA 1993c. *Great Lakes Water Quality Initiative Methodology for Development of Bioaccumulation Factors, B, Part 132.* 58:72 Federal Register 21022-21047 (April 16, 1993).

16. USEPA. 1993d. *Guideline on Air Quality Models, Appendix W.* US Environmental Protection Agency, July 1993.

17. USEPA. April 15, 1994d. *Risk Assessment Implementation Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes.* Revised Draft. Office of Emergency and Remedial Response and Office of Solid Waste.

18. USEPA. October 4, 1994e. Errata Sheet, *Risk Assessment and Implementation Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Revised Draft.* Office of Emergency and Remedial Response and Office of Solid Waste.

19. USEPA. 1994a. *Derivation of Time-Averages Soil Concentration Equations.* Office of Emergency and Remedial Response and Office of Solid Waste.

20. USEPA. 1994b. *Further Issues for Indirect Exposure Assessment Modeling.* Memorandum from Matthew Lorber, Exposure Assessment Group and Glen Rice, Indirect Exposure Team, to Addressees.

21. USEPA. 1994c. *Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children.* Office of Emergency and Remedial Response, Washington DC EPA/540/R-93/081.

22. USEPA. 1995a. *Guidance on Risk Characterization for Risk Managers and Risk Assessors.* Memorandum from F. Henry Habicht, Deputy Administrator, USEPA, to: Assistant Administrators.

23. USEPA. 1995b. *Users Guide for the Industrial Source Complex (ISC3) Dispersion Models.* US Environmental Protection Agency. September 1995.

Appendix B

USEPA Screening Evaluation Algorithms and Parameters

Step 1: USEPA IG Screening Evaluation
Soil Concentration Due to Deposition

Adult/Child Resident

(10) $$Sc = \frac{[(Ds * Tc - Sc(Tc)/ks] + [Sc(Tc)/ks * (1-exp(-ks*(T(2)-Tc)))]}{[T(2) - T(1)]}$$ ⇐ Carcinogenic substances

or

(10a) $$Sc(1) = \frac{Ds * Tc - Sc(Tc)}{ks * Tc}$$ and

(10b) $$Sc(2) = \frac{Sc(Tc) * [1 - exp(-ks * [T(2) - Tc])]}{ks * [T(2) - Tc]}$$

or

(11) $$Sc = \frac{Ds * [1-exp(-ks * Tc)]}{ks}$$ ⇐ Noncarcinogenic substances

(10a) $$Sc(Tc) = \frac{Ds * [1-exp(-ks * Tc)]}{ks}$$

(10b) $$Ds = \frac{100 * [(0.31536 * Vdv * Vc + Vwd) + (Pwd + Pdd)]}{Z * BD}$$

(10c) $$ks = ksl + ksr + kse + ksg + ksv$$

(10e) $$ksl = \frac{P + I - R - Ev}{Z * (\Theta s + Kds * BD)}$$

(10f) $$ksr = \frac{R}{Z * (\Theta s + Kds * BD)}$$

Parameter	Definition	Default/Site Specific Value
Sc	Soil concentration, mg/kg	calculated
Sc(1)	Average soil concentration over the period of deposition, unitless	calculated
Sc(2)	Average soil concentration over the period after deposition, unitless	calculated
ks	Soil loss concentration due to all processes, yr^{-1}	calculated
ksl	Loss constant due to leaching, yr^{-1}	calculated
ksr	Loss constant due to surface runoff, yr^{-1}	calculated
kse	Loss constant due to erosion, yr^{-1}	0
ksg	Loss constant due to degradation, yr^{-1}	chemical-specific
ksv	Loss constant due to volatilization, yr^{-1}	0
Pdd	= Q*Dydp*(1-Fv), Yearly dry deposition from particle phase for the ith SOPC, g/m^2-yr	modeled
Pwd	= Q*Dywp*(1-Fv), Yearly wet deposition from particle phase for the ith SOPC, g/m^2-yr	modeled
Vwd	= Q*Fv*Dywv, Yearly wet deposition from vapor phase for the ith SOPC, g/m^2-yr	modeled
Vc	= Q*Fv*Cyv, Yearly vapor phase air concentraion for the ith SOPC, $\mu g/m^2$	modeled
Vdv	Dry deposition velocity, cm/s	3
Kds	Soil-water partition coefficient, cm^3/g or mL/g	chemical-specific
Tc	Total deposition time period, yr	default: 30
Sc(Tc)	Soil concentration at time Tc, mg/kg	calculated
Ds	Deposition term, mg/kg-yr	calculated
T(1)	Time before deposition, yr	0

Parameter	Definition	Default/Site Specific Value
T(2)	Total exposure time period, yr	Farmer: 40 Fisher, adult: 30 Child: 6
Z	Soil mixing depth, cm	1
BD	Soil bulk density, g/cm^3	1.5
Ev	Average annual evapotranspiration, cm/yr	site-specific
P	Average annual precipitation, cm/yr	site-specific
I	Average annual irrigation, cm/yr	0
R	Average annual runoff, cm/yr	site-specific
Θs	Soil volumetric water content, cm^3/cm^3 or mL/cm^3	0.2
100	Units conversion factor, $mg\text{-}m^2/kg\text{-}cm^2$	

Step 1: USEPA IG Screening Evaluation
Above-ground Vegetable Concentration Due to Direct Deposition and Air-to-Plant Transfer

Adult/Child Resident

(12a) $$Pd = \frac{1000 * [Pdd + (Fw * Pwd)] * Rp * [1.0 - \exp(-kp * Tp)]}{Yp * kp}$$

(12b) $$Pv = \frac{Vc * Bv * VGag}{\rho(a)}$$

(12c) $$Pr(ag) = Sc * Br$$

Parameter	Definition	Default/Site-Specific Value
Pd	Concentration in plant due to direct deposition, mg/kg	calculated
Pv	Concentration in plant due to air-to-plant transfer, mg/kg	calculated
1000	Units conversion factor, mg/g	
Yp	Standing crop biomass of the edible portion of the plant, kg dry weight (DW)/m^2	1.7
Vc	Yearly vapor phase air concentration for the ith SOPC, $\mu g/m^2$	modeled
Pdd	= Q*Dydp*(1-Fv), Yearly dry deposition from particle phase for the ith SOPC, g/m^2-yr	modeled
Pwd	= Q*Dywp*(1-Fv), Yearly wet deposition from particle phase for the ith SOPC, g/m^2-yr	modeled
Fw	Wet deposition retention fraction, unitless	chemical-specific
kp	Plant surface loss coefficient, yr^{-1}	18
Tp	Length of plant exposure to depostion of edible portion of plant, per harvest, yr	0.16
VGag	Emperical correction factor for above-ground vegetable, unitless	0.01
Rp	Interception fraction of edible portion of plant, unitless	0.04
Bv	Air-to-plant biotransfer factor, (mg substance/kg plant tissue DW)/(μg substance/g air)	chemical-specific
Br	Plant-soil bioconcentration factor for the i^{th} plant group, (μg substance/g plant tissue DW)/(μg substance/g soil)	chemical-specific
ρ(a)	Density of air, g/m^3	$1.2x10^3$
Pr(ag)	Concentration of substance in above-ground plant parts due to root uptake, (mg/kg)	calculated

Parameter	Definition	Default/Site-Specific Value
Sc	Soil concentration, mg/kg	calculated from Eq. 10

Step 1: USEPA IG Screening Evaluation
Root Vegetable Due to Deposition and Root Uptake
Adult/Child Resident

(13) $$Pr(bg) = \frac{Sc * RCF * Vgbg}{Kds}$$

Parameter	Definition	Default/Site-Specific Value
Pr(bg)	Concentration in below-ground plant parts due to root uptake, mg/kg	calculated
Sc	Soil concentration, mg/kg	calculated from Eq. 10 using Z = 20 cm
RCF	Ratio of concentration in roots to concentration in soil pore water, (mg substance/kg plant tissue FW)/(μg substance/mL pore water)	chemical-specific
VGbg	Below-ground vegetable correction factor, unitless	0.01
Kds	Soil-water partition coefficent, cm^3/g or mL/g	chemical-specific

Step 1: USEPA IG Screening Evaluation
Fish Concentration

(14) $C(fish) = \frac{C(sb) * f(lipid) * BSAF}{OC(sed)}$ or

$C(fish) = C(dw) * BCF$ or

$C(fish) = C(wt) * BAF$

(14a) $Ds = \frac{100 * [(0.31536 * Vdv * Vcs + Vwds) + (Pwds + Pdds)]}{Z * BD}$

(14b) $kse = \frac{0.1 * Xe * SD * ER * (Kds * BD)}{BD * Z * [\Theta(s) + Kds * BD]}$

(14c) $L(T) = L(dep) + L(RI) + L(R) + L(E)$

(14d) $L(dep) = [Vwdb + Pddb + Pwdb] * WA(w)$

(14e) $L(RI) = [Vwds + Pdds + Pwds]] * WA(I)$

(14f) $L(R) = \frac{R * [WA(L)-WA(I)] * (Sc * BD) * 0.01}{(\Theta s + Kds * BD)}$

(14g) $L(E) = \frac{Xe * [WA(L)-WA(I)] * SD * ER * (Sc * Kds * BD) * 0.001}{(\Theta s + Kds * BD)}$

(14h) $Xe = \frac{RF * K * LS * C * P * 907.18}{4047}$

(14i) $SD = a * [WA(L)]^{-b}$

(14j) $C(wtot) = \frac{L(T)}{Vf(x) * f(water) * [[d(w)+d(b)]/d(w)] + kwt * WA(w) * [d(w)+d(b)]}$

(14k) $$f(water) = \frac{(1+Kdsw * TSS * 10^{-6}) * d(w)}{(1+Kdsw * TSS * 10^{-6}) * d(w)+[\Theta(bs)+Kdbs * BS] * d(b)}$$

(14l) $$f(benth) = 1- f(water)$$

(14m) $$kwt = \frac{f(benth) * [(Xe * SD * WA(L) * 1000) - (Vf(x) * TSS)]}{d(b) * WA(w) * BS * 10^{6}}$$

(14n) $$C(wt) = f(water) * C(wtot) * [[d(w) + d(b)]/d(w)]$$

(14o) $$C(dw) = \frac{C(wt)}{1 + Kdsw * TSS * 10^{-6}}$$

(14p) $$C(sb) = \frac{f(benth) * C(wtot) * (Kdbs) * [d(w)+d(b)]}{[\Theta(bs) + Kdbs * BS] * d(b)}$$

Parameter	Definition	Default/Site-Specific Value
Pwds	= Q*(1-Fv)*Dywwp; Yearly watershed wet depostion from particle phase for the ith SOPC, g/m2/yr	modeled
Pdds	= Q*(1-Fv)*Dydwp; Yearly watershed dry depostion from particle phase for the ith SOPC, g/m2/yr	modeled
Vwds	= Q*Fv*Dywwv; Yearly watershed wet depostion from vapor phase for the ith SOPC, g/m2/yr	modeled
Vcs	= Q*Fv*Cywwv; Yearly watershed average vapor phase air concentration for the ith SOPC, ug/m3	modeled
Pwdb	= Q*(1-Fv)*Dywp; Yearly waterbody wet depostion from particle phase for the ith SOPC, g/m2/yr	modeled
Pddb	= Q*(1-Fv)*Dydp; Yearly waterbody dry depostion from particle phase for the ith SOPC, g/m2/yr	modeled
Vwdb	= Q*Fv*Dywv; Yearly waterbody wet depostion from vapor phase for the ith SOPC, g/m2/yr	modeled
Vcb	= Q*Fv*Cywv; Yearly waterbody average vapor phase air concentration for the ith SOPC, ug/m3	modeled
kse	Loss constant due to soil erosion, yr^{-1}	calculated
0.1	Units conversion factor, $kg\text{-}cm^2/g\text{-}m^2$	
Xe	Unit soil loss, $kg/m^2\text{-}yr$	calculated
SD	Watershed sediment delivery ratio, unitless	calculated
ER	Soil enrichment ratio, unitless	3
Kds	Soil-water partition coefficient, L/kg	chemical-specific

Parameter	Definition	Default/Site-Specific Value
BD	Soil bulk density, g/cm^3	1.5
Z	Soil mixing depth, cm	1
L(T)	Total substance load to the waterbody, g/yr	calculated
L(dep)	Deposition of particle bound substance to the waterbody, g/yr	calculated
L(RI)	Runoff load from impervious surfaces, g/yr	calculated
L(R)	Runoff load from pervious surfaces, g/yr	calculated
L(E)	Soil erosion load, g/yr	calculated
WA(w)	Waterbody area, m^2	site-specific
WA(I)	Impervious watershed area, m^2	site-specific
0.01	Units conversion factor, $kg\text{-}cm^2/mg\text{-}m^2$	
R	Average annual runoff, cm/yr	site-specific
WA(L)	Total watershed area, m^2	site-specific
Sc	Soil concentration, mg/kg	calculated from Eq. 10 using Z = 1
0.001	Units conversion factor, (g/kg)/(mg/kg)	
RF	USLE rainfall (or erosivity) factor, 1/yr	site-specific
K	USLE erodibility factor, ton/acre	0.36
LS	USLE length-slope factor, unitless	1.5
C	USLE cover management factor, unitless	0.1
P	USLE supporting practice factor, unitless	1
907.18	Conversion factor, kg/ton	
4047	Conversion factor, km^2/acre	
b	Empirical slope coefficient, unitless	0.125
a	Empirical intercept coefficient, unitless	watershed area dependent

Parameter	Definition	Default/Site-Specific Value
C(wtot)	Total waterbody concentration, including water column and bed sediment, mg/L	calculated
Vf(x)	Average volumetric flow rate, m^3/yr	site-specific
f(water)	Fraction of total waterbody substance concentration that occurs in the water column, unitless	calculated
d(w)	Depth of the water column, m	site-specific
d(b)	Depth of upper benthic layer, m	0.03
Kdsw	Suspended sediment/surface water partition coefficient, L/kg	calculated
TSS	Total suspended solids, mg/L	10
10^{-6}	Units conversion factor, kg/mg	
Θbs	Bed sediment porosity, L water/L	0.5
BS	Bed sediment concentration, g/cm^3	1.0
f(benth)	Fraction of total waterbody substance concentration that occurs in the bed sediment, unitless	calculated
C(wt)	Total concentration in water column, mg/L	calculated
kwt	Total waterbody dissipation rate constant, yr^{-1}	calculated
C(dw)	Dissolved phase water concentration, mg/L	calculated
C(sb)	Concentration sorbed to bed sediments, mg/kg	calculated
Kdbs	Bottom sediment-sediment pore water partition coefficient, mg/kg	calculated
C(fish)	Concentration in fish, mg/kg	calculated
f(lipid)	Fish lipid content, unitless	0.07
OC(sed)	Fraction organic carbon in bottom sediment, unitless	0.04
BSAF	Biota to sediment accumulation factor, unitless	chemical-specific
BCF	Bioconcentration factor, L/kg	chemical-specific
BAF	Bioaccumulation factor, L/kg	chemical-specific

Step 1: USEPA IG Screening Evaluation

Soil Intake
Adult/Child Resident

(2a) $I(soil) = Sc * CR(soil) * F(soil)$

Above-ground Vegetable Intake
Adult/Child Resident

(4a) $I(ag) = [Pd + Pv + Pr] * CR(ag) * F(ag)$

Root Vegetable Intake
Adult/Child Resident

(4b) $I(bg) = Pr(bg) * CR(bg) * F(bg)$

Fish Intake
Adult/Child Resident

(6a) $I(fish) = C(fish) * CR(fish) * F(fish)$

Total Intake
Adult/Child Resident

(21) $I(tot) = I(soil) + I(ag) + I(bg)$

Parameter	Definition	Default/Site-Specific Value
I(soil)	Daily intake of substance from soil, mg/day	calculated
Sc	Soil concentration after total exposure period, mg/kg	calculated from Eq.10
CR(soil)	Consumption rate of soil, kg/day	Farmer, fisher, adult: 0.0001 Child: 0.0002
F(soil)	Fraction of soil impacted, unitless	1
I(bg)	Daily intake of substance from root vegetables, mg/day	calculated

CR(bg)	Consumption rate of root vegetables, kg/day	Farmer, fisher, adult: 0.0063 Child: 0.0014
F(bg)	Fraction of root vegetables impacted, unitless	Farmer: 0.95 Fisher, adult, child: 0.25
I(ag)	Daily intake of substance from above-ground vegetables, mg/day	calculated
Pd	Concentration in plant due to direct deposition, mg/kg	calculated from Eq. (1-7)
Pv	Concentration in plant due to air-to-plant transfer, mg/kg	calculated from Eq. (1-8)
CR(ag)	Consumption rate of above-ground vegetables, kg/day	Farmer, fisher, adult: 0.024 Child: 0.005
F(ag)	Fraction of above-ground vegetables impacted, unitless	Farmer: 0.95 Fisher, adult, child: 0.25
Pr(bg)	Concentration in plant due to root uptake, mg/kg	calculated from Eq. (13)
I(fish)	Daily intake of substance from fish, mg/kg	calculated
C(fish)	Concentration in fish, mg/kg	calculated from Eq. (14)
CR(fish)	Consumption rate of fish, kg/day	0.059
F(fish)	Fraction of fish impacted, unitless	1
C(dw)	Dissolved substance concentration in drinking water, mg/L	calculated from Eq. (14p)
I(tot)	Total daily inake of substance, mg/day	calculated

Step 1: USEPA IG Screening Evaluation
Cancer Risks, Hazard Quotients, and Hazard Indices Due to Indirect Exposures

Indirect Cancer Risk
Adult/Child Resident

(15) Indirect Cancer Risk $= \frac{I(tot) * ED * EF * CSF}{BW * AT * 365}$

Indirect Hazard Quotients
Adult/Child Resident

(1-17) $HQ = \frac{I(tot)}{BW * RfD}$

Indirect Hazard Index
Adult/Child Resident

(1-18) $HI = \sum HQ$

Indirect Hazard Index for Liver Effects
Adult/Child Resident

(1-19) $HI(liver) = \sum HQ(liver)$

Indirect Hazard Index for Neurotoxic Effects
Adult/Child Resident

(1-20) $HI(neuro) = \sum HQ(neuro)$

Total Indirect Cancer Risk
Adult/Child Resident

(1-21) Total Indirect Cancer Risk $= \sum$ Indirect Cancer Risks

Parameter	Definition	Default/Site-Specific Value
Indirect Cancer Risk	Excess lifetime cancer risk from indirect exposures, unitless	calculated
I(tot)	Total daily intake of substance, mg/day	calculated from Eq. 21
ED	Exposure duration	Farmer: 40 Fisher and adult: 30 Child: 6
EF	Exposure frequency, day/yr	350
CSF	Oral cancer slope factor, $(mg/kg\text{-}day)^{-1}$	chemical-specific
BW	Body weight, kg	Farmer, fisher, adult: 70 Child: 15
AT	Averaging time, yr	70
365	Units conversion factor, day/yr	
HQ	Hazard quotient from indirect exposures, unitless	calculated
RfD	Reference dose, mg/kg-day	chemical-specific
HI(liver)	Hazard index for liver effects, unitless	calculated
HI(neuro)	Hazard index for neurotoxic effects, unitless	calculated
HQ(liver)	Hazard quotient for substance with liver effects, unitless	calculated
HQ(neuro)	Hazard quotient for substance with neurotoxic effects, unitless	calculated

Step 1: USEPA IG Screening Evaluation
Intakes, Cancer Risk and Hazard Due to Inhalation, Grand Total Cancer Risk

Adult/Child Resident

Cancer Inhalation Intake

(1) Cancer Inhalation Intake $= \frac{\text{Respirable Concentration}*IR*ET*EF*ED*0.001}{BW * LT}$

Inhalation Cancer Risk

(15) Inhalation Cancer Risk = Cancer Inhalation Intake * Inhalation CSF

Inhalation Hazard Quotient

(16) $HQ(inh) = \frac{\text{Respirable Concentration} * 0.001}{RfC}$

Inhalation Hazard Index

(17a) $HI(inh) = \sum HQ(inh)$

Total Inhalation Cancer Risk

(18) Total inhalation Risk = $\sum$ Inhalation Cancer Risks

Grand Total Cancer Risk

(19) Grand Total Cancer Risk = Indirect Cancer Risk + Inhalation Cancer Risk

Inhalation Hazard Index for Target Organ

(20) $HI(inh)_{TO} = \sum HQ(inh)_{TO}$

Parameter	Definition	Default/Site-Specific Value
Cancer Inhalation Intake	Daily intake of carcinogenic substance from inhalation, mg/kg-day	calculated
Respirable Concentration	Total particulate concentration plus total vapor concentration, $\mu g/m^3$	modeled
IR	Inhalation rate, m^3/hr	Farmer, fisher, adult: 1.0 child: 0.2
ET	Exposure time, hr/day	24
EF	Exposure frequency, day/yr	350
ED	Exposure duration, yr	30
0.001	Units conversion factor, $mg/\mu g$	
BW	Body weight, kg	Farmer, fisher, adult: 70 child: 15
LT	Number of days in a lifetime, day	25550
Inhalation Cancer Risk	Excess lifetime cancer risk from inhalation, unitless	calculated
Inhalation CSF	Inhalation cancer slope factor, $(mg/kg\text{-}day)^{-1}$	chemical-specific
HQ(inh)	Hazard quotient for substance from inhalation, unitless	calculated
RfC	Inhalation reference concentration, mg/m^3	chemical-specific
$HI(inh)_{TO}$	Hazard index from inhalation for target organ, unitless	calculated
Grand Total Cancer Risk	Excess lifetime cancer risk from indirect exposure and direct inhalation, unitless	calculated

Appendix C

Propellant Bag Burning Data from 1986-1994

The following assumptions were made if this specific data was not recorded in the firing and burning records between 1986-1994:

1. Table C-1 lists the assumed charge and therefore the assumed number of increments that were burned for each round of artillery or mortar fired. These numbers were the most often noted charges found on the firing records.

Table C-1. Assumed Charge Load.

Artillery/Mortar	*Charge*
155-mm	3 (2 bags left over)
105-mm	4 (3 bags left over)
81-mm	4 (5 bags left over)
60-mm	3 (1 bag left over)
4.2-in (or 107-mm)	10 (31 "cheese" left over)

2. While the firing positions were not readily noted on the records, it was assumed that the same military unit stayed at the same firing positions for the same training day. Therefore, if one firing record had a designated firing point, this was used for all records marked with the same unit and date.

3. If a mortar record did not contain which type of mortar was fired, it was assumed to be an 81-mm mortar.

4. If an artillery record did not contain which type of artillery was fired, it was assumed to be a 155-mm howitzer.

Table C-2: M1 Propellant Burn Data for 1986

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
3-Jan-86	GP16	155mm	224	198.80
3-Jan-86	GP20	155mm	224	198.80
3-Jan-86	GP22	155mm	208	184.60
7-Feb-86	GP9	155mm	146	176.11
8-Feb-86	GP11	105mm	64	31.56
8-Feb-86	GP14	105mm	92	45.37
8-Feb-86	GP18	105mm	72	35.51
8-Feb-86	GP18	105mm	16	7.89
8-Feb-86	GP20	105mm	76	37.48
8-Feb-86	GP20	105mm	160	78.90
8-Feb-86	GP6	105mm	80	39.45
8-Feb-86	GP7	105mm	72	35.51
8-Feb-86	GP8	105mm	80	39.45
8-Feb-86	GP10	155mm	50	60.31
8-Feb-86	GP11	155mm	58	69.96
8-Feb-86	GP9	155mm	146	176.11
8-Feb-86	GP9	155mm	32	38.60
9-Feb-86	GP10	155mm	66	79.61
9-Feb-86	GP11	155mm	66	79.61
9-Feb-86	GP9	155mm	66	79.61
1-Mar-86	GP6	155mm	150	180.94
1-Mar-86	GP7	155mm	148	149.76
1-Mar-86	GP8	155mm	80	96.50
8-Mar-86	GP14	105mm	172	84.82
8-Mar-86	GP14	105mm	96	47.34
8-Mar-86	GP18	105mm	16	7.89
8-Mar-86	GP18	105mm	208	102.57
8-Mar-86	GP20	105mm	76	37.48
8-Mar-86	GP20	105mm	56	27.62
8-Mar-86	GP8	105mm	244	120.32
8-Mar-86	GP10	155mm	180	217.13
8-Mar-86	GP11	155mm	180	217.13
8-Mar-86	GP9	155mm	180	217.13
22-Mar-86	GP6	105mm	132	76.62
22-Mar-86	GP7	105mm	182	121.89
22-Mar-86	GP8	105mm	120	59.18
22-Mar-86	GP14	155mm	60	91.13
22-Mar-86	GP22	155mm	52	78.98
22-Mar-86	GP9	155mm	64	97.20
12-Apr-86	GP10	105mm	128	63.12
12-Apr-86	GP10	105mm	192	94.68
12-Apr-86	GP11	105mm	112	55.23
12-Apr-86	GP11	105mm	16	7.89
12-Apr-86	GP24	105mm	28	13.81
12-Apr-86	GP8	105mm	24	11.84
12-Apr-86	GP9	105mm	28	13.81
12-Apr-86	GP9	105mm	124	61.15
1-May-86	GP6	155mm	172	207.48
1-May-86	GP8	155mm	112	135.10
1-May-86	GP9	155mm	128	154.40
3-May-86	GP12	105mm	60	29.59
3-May-86	GP12	105mm	16	7.89
3-May-86	GP16	105mm	88	43.40
3-May-86	GP18	105mm	80	39.45
3-May-86	GP18	105mm	100	47.34
18-Oct-86	GP7	155mm	56	67.55
3-May-86	GP22	105mm	80	39.45
3-May-86	GP22	105mm	92	43.40
3-May-86	GP6	105mm	92	45.37
3-May-86	GP7	105mm	100	49.31
3-May-86	GP8	105mm	220	108.49
31-May-86	GP11	105mm	24	11.84
31-May-86	GP24	105mm	100	49.31
31-May-86	GP24	105mm	78	45.27
31-May-86	GP7	105mm	16	7.89
31-May-86	GP7	105mm	78	45.27
31-May-86	GP8	105mm	196	96.65
31-May-86	GP8	105mm	54	31.34
7-Jun-86	GP14	155mm	98	115.80
7-Jun-86	GP16	155mm	136	164.05
7-Jun-86	GP20	155mm	136	164.05
7-Jun-86	GP6	155mm	198	183.38
21-Jun-86	GP14	105mm	215	141.81
21-Jun-86	GP20	105mm	124	71.39
21-Jun-86	GP22	105mm	90	52.24
21-Jun-86	GP11	155mm	52	62.73
21-Jun-86	GP8	155mm	86	79.61
21-Jun-86	GP9	155mm	62	74.79
22-Jun-86	GP14	105mm	12	8.51
22-Jun-86	GP20	105mm	21	12.19
22-Jun-86	GP22	105mm	12	8.51
28-Jun-86	GP11	105mm	20	9.86
28-Jun-86	GP6	105mm	188	92.71
28-Jun-86	GP7	105mm	256	126.24
28-Jun-86	GP8	105mm	128	63.12
28-Jun-86	GP9	105mm	128	63.12
28-Jun-86	GP11	155mm	10	12.06
28-Jun-86	GP6	155mm	94	113.39
28-Jun-86	GP7	155mm	128	154.40
28-Jun-86	GP8	155mm	64	77.20
28-Jun-86	GP9	155mm	64	77.20
13-Sep-86	GP10	155mm	164	197.83
13-Sep-86	GP14	155mm	98	115.80
13-Sep-86	GP16	155mm	136	164.05
13-Sep-86	GP20	155mm	136	164.05
13-Sep-86	GP9	155mm	166	200.24
27-Sep-86	GP6	105mm	148	72.98
27-Sep-86	GP7	105mm	152	74.96
27-Sep-86	GP8	105mm	20	9.86
27-Sep-86	GP8	105mm	132	65.09
4-Oct-86	GP10	155mm	128	154.40
4-Oct-86	GP11	155mm	100	120.63
4-Oct-86	GP14	155mm	56	67.55
4-Oct-86	GP17	155mm	68	82.03
4-Oct-86	GP18	155mm	68	82.03
4-Oct-86	GP20	155mm	80	96.50
4-Oct-86	GP22	155mm	56	67.55
4-Oct-86	GP24	155mm	104	125.45
4-Oct-86	GP6	155mm	82	98.91
4-Oct-86	GP7	155mm	82	98.91
18-Oct-86	GP6	155mm	256	308.80
18-Oct-86	GP8	155mm	52	62.73

25-Oct-86	GP10	155mm	48	57.90
25-Oct-86	GP9	155mm	92	118.21
1-Nov-86	GP12	105mm	96	47.34
1-Nov-86	GP14	105mm	128	63.12
1-Nov-86	GP16	105mm	128	63.12
1-Nov-86	GP18	105mm	16	7.89
1-Nov-86	GP9	155mm	14	21.26
1-Nov-86	GP9	155mm	11	16.71
1-Nov-86	GP9	155mm	7	10.63
1-Nov-86	GP9	155mm	6	9.11
1-Nov-86	GP9	155mm	4	6.08
1-Nov-86	GP9	155mm	4	6.08
1-Nov-86	GP9	155mm	4	6.08
1-Nov-86	GP9	155mm	3	4.56
1-Nov-86	GP9	155mm	3	4.56
1-Nov-86	GP9	155mm	3	4.56
22-Nov-86	GP16	155mm	200	241.25
22-Nov-86	GP22	155mm	192	231.60

Table C-3: M9 Propellant Burn Data for 1986

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
3-Jan-86	MP1	60mm	326	2.04
11-Jan-86	MP1	60mm	125	0.78
11-Jan-86	MP4	81mm	1170	27.24
8-Feb-86	MP4	81mm	250	5.82
8-Feb-86	MP7	81mm	1055	24.57
9-Feb-86	MP2	81mm	220	5.12
8-Mar-86	MP4	81mm	435	10.13
8-Mar-86	MP2	107mm	1240	20.75
22-Mar-86	MP4	81mm	132	3.07
23-Mar-86	MP6	81mm	380	8.85
5-Apr-86	MP3	107mm	1550	25.94
19-Apr-86	MP1	81mm	25	0.58
19-Apr-86	MP2	81mm	80	1.86
3-May-86	MP1	81mm	500	11.64
3-May-86	MP3	107mm	1240	20.75
10-May-86	MP4	81mm	400	9.31
17-May-86	MP3	60mm	7	0.04
19-May-86	MP6	81mm	500	11.64
20-May-86	MP6	81mm	450	10.48
7-Jun-86	MP3	81mm	50	1.16
9-Jun-86	MP7	81mm	750	17.46
21-Jun-86	MP2	81mm	462	10.76
21-Jun-86	MP4	107mm	1500	25.10
11-Aug-86	MP2	81mm	550	12.81
12-Aug-86	MP2	81mm	750	17.46
12-Aug-86	MP3	81mm	270	6.29
12-Aug-86	MP5	107mm	800	13.39
13-Aug-86	MP3	60mm	55	0.34
14-Aug-86	MP1	81mm	385	8.97
14-Aug-86	T-Range	81mm	695	16.18
14-Aug-86	MP3	107mm	6696	112.06
14-Aug-86	MP5	107mm	1333	22.31
15-Aug-86	MP1	81mm	540	12.57
15-Aug-86	MP3	107mm	5580	93.39
15-Aug-86	MP5	107mm	620	10.38
16-Aug-86	MP3	60mm	104	0.65
16-Aug-86	MP1	81mm	920	21.42
16-Aug-86	MP3	81mm	250	5.82
16-Aug-86	MP3	107mm	744	12.45
18-Aug-86	MP4	107mm	279	4.67
19-Aug-86	MP1	81mm	332	7.73
19-Aug-86	MP3	81mm	235	5.47
19-Aug-86	MP4	107mm	900	15.06
20-Sep-86	MP6	81mm	1530	142.51
4-Oct-86	MP2	81mm	755	17.58
4-Oct-86	MP3	81mm	1302	30.32
4-Oct-86	MP4	81mm	90	2.10
5-Oct-86	MP6	81mm	360	8.38
1-Nov-86	MP2	81mm	388	9.03
22-Nov-86	IBC	60mm	70	0.44
22-Nov-86	MP4	60mm	117	0.73
22-Nov-86	MP3	107mm	3596	60.18
22-Nov-86	MP6	107mm	1550	25.94

Table C-4: M1 Propellant Burn Data for 1987

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
7-Feb-87	GP18	105mm	16	7.89
7-Feb-87	GP14	105mm	128	63.12
7-Feb-87	GP12	105mm	96	47.34
7-Feb-87	GP7	105mm	224	110.46
7-Feb-87	GP8	105mm	256	126.24
8-Feb-87		155mm	320	386.00
7-Mar-87	GP8	105mm	72	35.51
7-Mar-87	GP7	105mm	104	51.29
7-Mar-87	GP6	105mm	88	43.40
7-Mar-87	GP14	105mm	90	52.24
7-Mar-87	GP9	155mm	36	43.43
7-Mar-87	GP10	155mm	36	43.43
7-Mar-87	GP11	155mm	44	53.08
2-May-87		155mm	146	221.74
2-May-87		155mm	294	354.64
16-May-87		155mm	352	424.60
18-Sep-87		155mm	240	289.50
26-Sep-87		155mm	354	427.01
3-Oct-87		155mm	324	390.83
17-Oct-87		155mm	154	185.76

Table C-5: M9 Propellant Burn Data for 1987

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
7-Mar-87	MP4	81mm	225	5.24
15-Nov-87	MP3	81mm	3840	89.42
17-Nov-87		60mm	146	0.91
17-Nov-87		107mm	2378	39.80
21-Nov-87	MP1	60mm	163	1.02
21-Nov-87	MP3	81mm	230	5.36
21-Nov-87	MP4	107mm	230	3.85

Table C-6: M1 Propellant Burn Data for 1988

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
4-Mar-88		155mm	70	84.45
16-Mar-88		155mm	46	55.49
19-Mar-88		155mm	332	400.54
14-Apr-88		155mm	24	28.95
16-Apr-88		155mm	292	352.26
23-Apr-88		155mm	270	325.45
5-May-88		155mm	40	48.27
14-May-88		155mm	156	188.23
21-May-88		155mm	92	110.99
25-Jun-88		155mm	168	202.69
15-Oct-88		155mm	191	272.63
5-Nov-88		155mm	532	641.87

Table C-7: M9 Propellant Burn Data for 1988

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
23-Apr-88		107mm	930	15.61
23-Apr-88	MP1	60mm	38	0.64
10-May-88		107mm	558	9.37
14-May-88		107mm	3224	54.12
14-May-88		81mm	495	11.53
27-Jun-88		107mm	372	6.24
27-Jun-88		60mm	49	0.82
27-Jun-88		81mm	160	3.73
28-Jun-88		107mm	62	1.04
28-Jun-88		81mm	665	15.49
29-Jun-88		81mm	465	10.83
30-Jun-88		60mm	25	0.42
30-Jun-88		81mm	520	12.11
1-Jul-88		107mm	1085	18.21
1-Jul-88		81mm	495	11.53
2-Jul-88		81mm	640	14.90
27-Jul-88		60mm	29	0.49
27-Jul-88		81mm	320	7.45
28-Jul-88		81mm	855	19.91
30-Jul-88	MP6	81mm	1265	29.46
31-Jul-88		81mm	155	3.61
15-Oct-88		107mm	186	3.12
29-Oct-88		81mm	300	6.99
30-Oct-88		81mm	85	1.98
5-Nov-88		107mm	3317	55.68
5-Nov-88		81mm	395	9.20

Table C-8: M1 Propellant Burn Data for 1989

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
1989	GP6	155mm	351	357.58
1989	GP7	155mm	252	303.98
1989	GP8	155mm	140	168.88
1989	GP9	155mm	270	275.06
1989	GP10	155mm	324	390.83
1989	GP11	155mm	288	347.40
1989	GP12	155mm	150	180.94
1989	GP14	155mm	224	270.20
1989	GP16	155mm	364	439.08
1989	GP17	155mm	86	103.74
1989	GP18	155mm	86	103.74
1989	GP20	155mm	516	525.68
1989	GP22	155mm	552	562.35

Table C-9: M9 Propellant Burn Data for 1989

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
1989	MP1	60mm	452	3.81
1989	MP1	81mm	4278	99.62
1989	MP2	107mm	23232	389.97
1989	MP2	60mm	186	1.57
1989	MP2	81mm	1758	40.94
1989	MP3	107mm	12375	207.72
1989	MP3	81mm	3270	76.14
1989	MP4	107mm	23925	401.60
1989	MP4	81mm	4278	99.62
1989	MP5	107mm	6468	108.57
1989	MP5	81mm	1002	23.33
1989	MP6	81mm	3522	82.01
1989	MP7	81mm	4026	93.75
1989	MP8	81mm	3042	70.84

Table C-10: M1 Propellant Burn Data for 1990

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
03-Mar-90	GP6	155mm	32	38.60
03-Mar-90	GP7	155mm	138	166.46
24-Mar-90	GP6	155mm	118	142.34
24-Mar-90	GP7	155mm	96	115.80
24-Mar-90	GP9	155mm	80	96.50
24-Mar-90	GP10	155mm	77	92.32
24-Mar-90	GP16	155mm	46	69.86
24-Mar-90	GP18	155mm	88	107.40
24-Mar-90	GP20	155mm	92	110.98
07-Apr-90	GP6	155mm	32	38.60
07-Apr-90	GP7	155mm	48	48.90
07-Apr-90	GP8	155mm	32	38.60
07-Apr-90	GP14	155mm	50	60.31
07-Apr-90	GP20	155mm	68	82.03
07-Apr-90	GP22	155mm	42	50.66
28-Apr-90	GP14	155mm	92	110.98
28-Apr-90	GP22	155mm	10	12.06
05-May-90	GP6	155mm	24	28.95
05-May-90	GP7	155mm	48	48.90
05-May-90	GP8	155mm	24	28.95

Table C-11: M9 Propellant Burn Data for 1990

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
17-Mar-90	MP1	81mm	167	3.89
17-Mar-90	MP2	81mm	162	3.77
07-Apr-90	MP4	81mm	261	6.08
07-Apr-90	MP7	60mm	54	0.34
21-Apr-90	MP1	60mm	96	0.60
21-Apr-90	MP7	60mm	65	0.41
28-Apr-90	MP1	81mm	48	1.12
28-Apr-90	MP7	81mm	25	0.58
05-May-90	MP1	81mm	180	4.19
05-May-90	MP3	81mm	672	15.65
05-May-90	MP6	81mm	610	14.20
05-May-90	MP7	107mm	2332	39.14
05-May-90	MP8	81mm	560	13.04
10-Jun-90	MP1	81mm	884	20.58
10-Jun-90	T-Range	81mm	174	4.05
02-Aug-90	MP1	60mm	308	1.93

Table C-12: M1 Propellant Burn Data for 1991

Date of Firing	Gun Point	Artillery Type	Propellant Weight Burned (lbs)
9-Mar-91	GP-10	155mm	82.030
9-Mar-91	GP-11	155mm	79.610
9-Mar-91	GP-9	155mm	79.610
23-Mar-91	GP-11	155mm	125.450
23-Mar-91	GP-12	155mm	120.650
23-Mar-91	GP-14	155mm	33.750
23-Mar-91	GP-16	155mm	139.930
23-Mar-91	GP-20	155mm	144.750
23-Mar-91	GP-7	155mm	125.450
23-Mar-91	GP-9	155mm	110.975
14-Apr-91	GP-10	155mm	193.000
14-Apr-91	GP-11	155mm	96.450
14-Apr-91	GP-9	155mm	193.000
20-Apr-91	GP-14	155mm	82.025
20-Apr-91	GP-16	155mm	79.610
20-Apr-91	GP-20	155mm	79.610
23-Apr-91	GP-6	105mm	96.730
24-Apr-91	GP-6	105mm	89.520
24-Apr-91	GP-6	105mm	145.820
25-Apr-91	GP-6	105mm	49.090
25-Apr-91	GP-8	105mm	28.875
26-Apr-91	GP-8	105mm	43.310
27-Apr-91	GP-6	105mm	67.860
28-Apr-91	GP-8	105mm	15.880
29-Apr-91	GP-6	105mm	79.410
4-May-91	GP-6	155mm	48.250
4-May-91	GP-7	155mm	79.610
4-May-91	GP-8	155mm	45.750
5-Jun-91	GP-10	155mm	55.490
5-Jun-91	GP-6	155mm	50.660
5-Jun-91	GP-8	155mm	36.190
6-Jun-91	GP-17	155mm	21.710
6-Jun-91	GP-24	155mm	19.300
6-Jun-91	GP-6	155mm	38.600
6-Jun-91	GP-8	155mm	60.310
7-Jun-91	GP-14	155mm	50.660
7-Jun-91	GP-17	155mm	67.550
7-Jun-91	GP-24	155mm	24.125
8-Jun-91	GP-14	155mm	84.440
8-Jun-91	GP-20	155mm	50.660
8-Jun-91	GP-22	155mm	45.830
8-Jun-91	GP-6	155mm	38.600
8-Jun-91	GP-7	155mm	38.600
8-Jun-91	GP-8	155mm	38.600
9-Jun-91	GP-14	155mm	147.160
9-Jun-91	GP-20	155mm	55.490
9-Jun-91	GP-22	155mm	139.930
5-Oct-91	GP-17	155mm	62.730
5-Oct-91	GP-20	155mm	82.030
5-Oct-91	GP-22	155mm	57.900
5-Oct-91	GP-22	155mm	69.960

Table C-13: M9 Propellant Burn Data for 1991

Date of Firing	Mortar Point	Mortar Type	Propellant Weight Burned (lbs)
2-Jan-91	MP-1	107mm	26.970
7-Mar-91	MP-6	60mm	0.067
8-Mar-91	MP-3	60mm	0.135
16-Mar-91	MP-1	81mm	3.260
16-Mar-91	MP-3	60mm	1.990
6-Apr-91	MP-1	60mm	0.093
6-Apr-91	MP-1	81mm	7.990
6-Apr-91	MP-4	60mm	0.034
6-Apr-91	MP-6	60mm	1.854
6-Apr-91	MP-7	60mm	5.600
6-Apr-91	MP-8	60mm	31.650
20-Apr-91	MP-1	81mm	1.547
20-Apr-91	MP-2	107mm	6.861
24-Apr-91	MP-1	60mm	0.759
25-Apr-91	MP-1	107mm	21.610
27-Apr-91	MP-3	81mm	3.400
28-Apr-91	MP-3	81mm	0.955
29-Apr-91	MP-1	60mm	0.236
29-Apr-91	MP-1	60mm	2.520
29-Apr-91	MP-3	81mm	2.003
4-May-91	MP-1	107mm	17.154
4-May-91	MP-2	81mm	0.953
4-May-91	MP-3	107mm	30.876
4-May-91	MP-4	107mm	30.876
4-May-91	MP-4	81mm	1.589
4-May-91	MP-4	81mm	30.720
4-May-91	MP-6	60mm	1.050
4-May-91	MP-7	81mm	9.530
4-May-91	MP-8	81mm	17.854
1-Jun-91	MP-1	60mm	0.838
1-Jun-91	MP-3	60mm	1.800
1-Jun-91	MP-3	81mm	13.720
5-Jun-91	MP-1	107mm	19.210
6-Jun-91	MP-1	107mm	48.030
8-Jun-91	MP-1	60mm	2.013
17-Jun-91	MP-1	81mm	3.810
18-Jun-91	MP-1	81mm	14.090
18-Jun-91	MP-2	60mm	0.330
18-Jun-91	MP-3	107mm	9.260
18-Jun-91	MP-4	107mm	0.340
18-Jun-91	MP-4	107mm	34.310
18-Jun-91	MP-7	81mm	4.450
18-Jun-91	T-Range	81mm	2.750
19-Jun-91	IBC	60mm	1.940
19-Jun-91	IBC	81mm	0.320
19-Jun-91	MP-3	107mm	59.350
19-Jun-91	MP-6	107mm	109.450
19-Jun-91	MP-6	81mm	1.910
19-Jun-91	MP-7	107mm	37.740
19-Jun-91	MP-7	81mm	91.140
20-Jun-91	T-Range	81mm	16.040
21-Jun-91	MP-3	60mm	1.640
21-Jun-91	MP-3	81mm	13.200
22-Jun-91	MP-3	107mm	20.930
22-Jun-91	MP-3	81mm	12.920
22-Jun-91	MP-4	107mm	17.150
22-Jun-91	T-Range	81mm	11.500
23-Jun-91	MP-1	81mm	18.750
23-Jun-91	MP-2	81mm	3.180
23-Jun-91	MP-3	107mm	100.860
23-Jun-91	MP-4	81mm	57.910
23-Jun-91	T-Range	81mm	4.490
24-Jun-91	MP-1	81mm	3.180
24-Jun-91	MP-1	81mm	50.530
24-Jun-91	MP-3	107mm	134.290
15-Jul-91	IBC	60mm	1.500
17-Jul-91	MP-3	60mm	24.590
19-Jul-91	MP-1	60mm	0.300
19-Jul-91	MP-3	60mm	1.000
22-Jul-91	MP-1	81mm	1.800
23-Jul-91	MP-3	107mm	6.520
23-Jul-91	MP-4	81mm	43.130
24-Jul-91	IBC	81mm	50.660
24-Jul-91	MP-3	107mm	10.640
24-Jul-91	MP-7	107mm	2.740
25-Jul-91	MP-3	107mm	99.170
27-Jul-91	MP-1	81mm	49.490
29-Jul-91	IBC	81mm	4.450
29-Jul-91	MP-8	60mm	2.940
1-Aug-91	MP-1	60mm	0.830
7-Aug-91	MP-1	81mm	11.870
12-Aug-91	MP-1	81mm	12.280
7-Sep-91	MP-1	81mm	25.610
5-Oct-91	MP-1	107mm	13.723
5-Oct-91	MP-1	81mm	12.171
5-Oct-91	MP-3	107mm	3.360
5-Oct-91	MP-3	81mm	2.540
5-Oct-91	MP-4	81mm	6.360
5-Oct-91	MP-7	60mm	0.713
5-Oct-91	MP-9	81mm	5.080
19-Oct-91	MP-1	60mm	0.989
2-Nov-91	MP-1	60mm	1.250
2-Nov-91	MP-1	81mm	4.240
2-Nov-91	MP-3	60mm	0.488
2-Nov-91	MP-4	81mm	4.766
2-Nov-91	MP-5	81mm	0.110
2-Nov-91	MP-8	60mm	0.975
23-Nov-91	MP-4	81mm	5.300

Table C-14: M9 Propellant Burn Data for 1992

Date of Firing	Mortar Point	Mortar Type	Propellant Weight Burned (lbs)
3-Mar-92	MP-1	81mm	0.110
3-Mar-92	MP-3	60mm	0.050
3-Mar-92	MP-6	60mm	0.025
15-Mar-92	MP-3	81mm	9.530
21-Mar-92	MP-6	81mm	0.110
22-Mar-92	MP-5	81mm	3.810
22-Mar-92	MP-6	81mm	7.940
4-Apr-92	MP-1	81mm	4.240
4-Apr-92	MP-2	81mm	9.750
4-Apr-92	MP-3	81mm	1.800
4-Apr-92	MP-4	107mm	12.010
4-Apr-92	MP-5	60mm	0.625
4-Apr-92	MP-6	81mm	10.590
4-Apr-92	MP-7	60mm	0.800
5-Apr-92	MP-3	81mm	2.220
5-Apr-92	MP-4	107mm	5.150
5-Apr-92	MP-8	60mm	2.700
11-Apr-92	MP-1	81mm	11.020
11-Apr-92	MP-8	81mm	14.830
2-May-92	MP-1	81mm	7.690
2-May-92	MP-1	81mm	3.070
2-May-92	MP-2	107mm	27.790
2-May-92	MP-3	60mm	0.750
2-May-92	MP-4	107mm	0.340
2-May-92	MP-5	81mm	15.460
2-May-92	MP-6	60mm	1.610
2-May-92	MP-7	60mm	7.170
11-May-92	MP-8	81mm	13.770
16-May-92	MP-2	60mm	0.750
16-May-92	MP-4	81mm	12.980
26-May-92	MP-1	81mm	7.380
26-May-92	MP-2	81mm	6.570
26-May-92	MP-3	81mm	26.590
30-May-92	MP-3	81mm	26.400
6-Jun-92	MP-8	60mm	1.450
6-Jun-92	MP-8	81mm	2.000
13-Jun-92	MP-7	60mm	3.360
19-Jun-92	MP-8	81mm	11.120
27-Jun-92	MP-4	81mm	49.870
11-Jul-92	MP-3	81mm	13.990
27-Jul-92	MP-7	81mm	11.210
27-Jul-92	MP-8	81mm	2.430
24-Aug-92	MP-8	81mm	2.790
9-Sep-92	MP-8	60mm	6.860
10-Sep-92	MP-5	60mm	0.950
10-Sep-92	MP-6	81mm	7.080
10-Sep-92	MP-8	81mm	8.920
12-Sep-92	MP-1	81mm	10.800
3-Oct-92	MP-8	107mm	17.290
21-Oct-92	MP-8	60mm	3.070
21-Oct-92	MP-8	81mm	8.900
7-Nov-92	MP-2	60mm	1.390
7-Nov-92	MP-4	81mm	3.920
7-Nov-92	MP-6	60mm	0.760
7-Nov-92	MP-7	60mm	0.860

Table C-15: M9 Propellant Burn Data for 1993

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
1-Jan-93	MP-3	81mm	839	19.54
1-Jan-93	MP-4	81mm	60	0.28
6-Jan-93	MP-4	81mm	330	1.54
6-Jan-93	MP-4	81mm	2080	49.97
6-Jan-93	MP-5	60mm	554	3.46
6-Jan-93	MP-6	60mm	680	4.25
7-Jan-93	MP-5	60mm	454	2.84
7-Jan-93	MP-6	60mm	422	2.64
7-Jan-93	MP-8	81mm	515	4.34
31-Mar-93	MP-8	60mm	72	0.45
31-Mar-93	MP-8	81mm	375	7.94
3-Apr-93	MP-3	60mm	680	13.22
3-Apr-93	MP-4	60mm	88	0.6
3-Apr-93	MP-5	81mm	450	10.48
24-Apr-93	MP-2	81mm	197	0.46
24-Apr-93	MP-3	81mm	243	5.66
30-Apr-93	MP-5	81mm	756	17.6
1-May-93	MP-4	81mm	185	3.92
1-May-93	MP-6	107mm	3836	63.23
1-May-93	MP-8	81mm	630	13.35
2-May-93	MP-4	81mm	340	7.2
10-May-93	MP-8	60mm	200	1.26
10-May-93	MP-8	60mm	536	3.37
15-May-93	MP-3	60mm	680	12.84
15-May-93	MP-5	107mm	840	14.41
5-Jun-93	MP-3	60mm	590	7.33
5-Jun-93	MP-6	81mm	347	8.08
12-Jun-93	MP-3	107mm	2000	34.31
12-Jun-93	MP-7	60mm	186	1.17
22-Jun-93	MP-2	81mm	30	0.7
24-Jun-93	MP-1	81mm	516	12.02
24-Jun-93	MP-2	81mm	180	8.38
24-Jun-93	MP-3	107mm	320	20.59
25-Jun-93	MP-2	81mm	410	9.55
26-Jun-93	MP-2	81mm	727	16.93
26-Jun-93	MP-3	107mm	800	19.9
26-Jun-93	MP-8	81mm	750	20.97
27-Jun-93	MP-8	81mm	438	10.2
28-Jun-93	MP-3	107mm	846	14.41
28-Jun-93	MP-8	81mm	1253	29.81
30-Jun-93	MP-3	107mm	438	10.2
13-Jul-93	MP-8	81mm	156	3.63
16-Jul-93	MP-7	107mm	269	4.52
16-Jul-93	MP-8	81mm	195	9.65
16-Jul-93	MP-8	107mm	450	7.55
17-Jul-93	MP-4	107mm	1080	18.53
17-Jul-93	MP-4	107mm	540	9.26
17-Jul-93	MP-8	81mm	505	5.83
18-Jul-93	MP-4	107mm	2805	47.08
18-Jul-93	MP-4	81mm	505	10.7
18-Jul-93	MP-8	81mm	150	3.18
19-Jul-93	MP-1	107mm	480	10.29
19-Jul-93	MP-3	81mm	600	10.17
20-Jul-93	MP-1	107mm	660	11.32
20-Jul-93	MP-4	81mm	270	18.53
24-Jul-93	MP-8	81mm	576	13.41
28-Jul-93	MP-3	81mm	155	1.09
30-Jul-93	MP-1	60mm	20	0.41
30-Jul-93	MP-1	81mm	619	14.41
30-Jul-93	MP-3	60mm	24	0.46
31-Jul-93	MP-1	60mm	24	0.15
31-Jul-93	MP-1	81mm	42	0.7
31-Jul-93	MP-3	60mm	24	0.15
31-Jul-93	MP-3	81mm	30	0.7
1-Aug-93	MP-3	60mm	48	0.34
2-Aug-93	MP-3	60mm	48	0.34

Table C-16: M9 Propellant Burn Data for 1994

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
05-Feb-94	mp7	81mm	220	5.12
06-Feb-94	mp4	81mm	436	10.15
09-Apr-94	mp6	81mm	682	15.88
17-Apr-94	mp2	107mm	1666	27.88
30-Apr-94	mp3	81mm	360	8.38
14-May-94	mp3	81mm	294	6.85
14-May-94	mp4	81mm	294	6.85
14-May-94	mp1	81mm	294	6.85
14-May-94		81mm	7	0.16
14-May-94		81mm	126	2.93
14-May-94		81mm	119	2.77
14-May-94		81mm	7	0.16
14-May-94		81mm	119	2.77
14-May-94		81mm	84	1.96
14-May-94		81mm	114	2.65
14-May-94		81mm	84	1.96
14-May-94		81mm	186	4.33
14-May-94		81mm	140	3.26
14-May-94		81mm	5	0.12
14-May-94		81mm	5	0.12
14-May-94		81mm	20	0.47
14-May-94		81mm	60	1.40
14-May-94		81mm	60	1.40
14-May-94		81mm	30	0.70
14-May-94		81mm	60	1.40
15-May-94		81mm	175	4.08
15-May-94		81mm	21	0.49
15-May-94		81mm	54	1.26
05-Jun-94	mp3	81mm	242	5.64
20-Jun-94	mp1	107mm	272.375	4.56
20-Jun-94	mp3	81mm	20	0.47
20-Jun-94	mp4	81mm	186	4.33
21-Jun-94	mp2	107mm	398.875	6.68
21-Jun-94	mp1	107mm	408	6.83
21-Jun-94	mp3	81mm	119	2.77
21-Jun-94	mp1	81mm	60	1.40
22-Jun-94	mp4	81mm	136	3.17
24-Jun-94	mp3	81mm	54	1.26
25-Jun-94	mp6	81mm	38	0.88
25-Jun-94	mp4	81mm	29	0.68
25-Jun-94	mp4	81mm	2	0.05
26-Jun-94	mp1	107mm	397.125	6.65
26-Jun-94	mp4	81mm	100	2.33
26-Jun-94	mp4	81mm	40	0.93
26-Jun-94	mp6	81mm	40	0.93
26-Jun-94	mp6	81mm	102	2.38
11-Jul-94	mp6	81mm	267	6.22
24-Aug-94	mp8	60mm	60	0.38
24-Aug-94	mp8	81mm	183	4.26
30-Aug-94	mp8	60mm	56	0.35
30-Aug-94	mp8	81mm	54	1.26
09-Sep-94	mp6	81mm	525	12.23
10-Sep-94	mp7	81mm	352	8.20
10-Sep-94	mp3	81mm	377	8.78
10-Sep-94	mp8	81mm	610	14.20
11-Sep-94	mp7	81mm	252	5.87
12-Sep-94	mp3	107mm	481.875	8.06
08-Nov-94	mp8	60mm	340	2.13
09-Nov-94	mp8	81mm	217	5.05
10-Nov-94	mp8	81mm	325	7.57
20-Nov-94	mp3	81mm	388	9.03